Geodiversity Audit for Jersey

National Geoscience Programme

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BRITISH GEOLOGICAL SURVEY

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Foreword

The Bailiwick of Jersey has a rich geological history, which, together with bedrock sites in Normandy, Brittany and the other Channel Islands, tells the story of the Cadomian Orogeny, which took place in the Ediacaran (late Precambrian), and the tectonic events that followed during the lower Palaeozoic. Its more recent Quaternary deposits reflect climate change and provide extraordinary insight into the early human history of this part of the world.

The rich variety of geology provides for a varied landscape, from the low ground, underlain by the comparatively soft sedimentary rocks, to the rocky, dramatic coastlines composed of igneous rocks. Deeply incised valleys cross the Island from north to south and coastal cliff lines hint at a complex series of climatic and tectonic events. Extractive industries have left their mark in the form of quarries, many of which are now only known due to the building stones used across the Island.

This study has highlighted the richness and international importance of the archaeological record preserved within recent Quaternary geological deposits. The widespread distribution, relative accessibility and vivid story of prehistoric life and climate change in the past environments of the region indicate that Jersey's recent geological record is of exceptional scientific and public interest.

This study has provided a recommended set of sites to be considered for designation as Sites of Special Interest (SSIs), Special Landscape Areas (SLAs) and Prehistoric Landscape Zones (PLZs) to allow the rich diversity of these sites to be explored, appreciated, learned from and conserved for future generations.

Jersey Heritage's commitment to the conservation of the geodiversity of the Island has manifested itself through their funding of this audit and through their desire to influence the next Island Plan to give geodiversity sites protection through the planning system.

Acknowledgements

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Maps and diagrams have been prepared by the authors, except where stated otherwise. Photographs are by members of the BGS staff, BGS©UKRI, except where others are individually credited. This report also includes mapping data licensed from Jersey Heritage.

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Summary

This report describes a geodiversity audit of Jersey commissioned by Jersey Heritage and carried out by the British Geological Survey (BGS), with contributions from Matthew Pope (UCL Institute of Archaeology), Martin Bates (University of Wales Trinity St David's) and John Renouf.

The audit began with a review of the available geodiversity documentation for Jersey, including a BGS geological map and the accompanying book, digital aerial photography and publications, existing SSI documentation, site information from the Jersey States and guidebooks and websites describing the geology of the Island.

Around forty sites from the initial list were visited and audited, mostly during September and October 2019. During site visits, the geological scientific merit, education value, community site value, cultural/heritage/economic importance, access, site fragility and potential were assessed.

To date, Jersey has designated 22 SSIs that are of geological interest. This study recommends a further 11 sites, which, supported by nine additional sites proposed as '2nd Tier' sites, tell the story of Jersey's geological and prehistoric history. These sites show the typical geological strata, structure and features of all the geological units present immediately beneath the surface of Jersey and together tell the story of the geology of Jersey. The sites, chosen primarily for their geology, have revealed numerous links to the character of the landscape, historical structures, ecology and the economic and cultural history of the area.

Many of these sites could be enhanced to encourage visitors and students to learn more about the geology beneath their feet and how this geology, as the foundation of our landscape, has influenced the form and nature of what lies at the surface.

This report will assist in future planning involving development and conservation issues within Jersey and will help to inform the Jersey Island Plan and to underpin any future aspirations for Geopark status.

1 Introduction

This report is the published product of a study led by the British Geological Survey (BGS) on behalf of Jersey Heritage. The aim of the study was to recommend a suite of sites for consideration as Sites of Special Interest (SSIs) and Special Landscape Areas (SLAs). In addition, it proposes that for parts of the Island preserving Quaternary archaeology and palaeoenvironmental records at scale, a series of Prehistoric Landscape Zones (PLZs) should be defined and managed alongside specific prehistoric sites. In these ways, Jersey's rich geological diversity can be explored, appreciated, learned from and conserved for future generations. The results of the audit can be used to inform the development of the next Island Plan, the spatial planning framework for Jersey, and also to provide geological information and a context to underpin Jersey's aspirations to develop a UNESCO Global Geopark.

The audit area extends around the whole of the Bailiwick of Jersey, which includes many islands and reefs, including Les Écréhous, the Paternosters and Les Minquiers (Figure 1), as well as the wider seabed. The project ran from September 2019 until July 2020, with a planning visit to the Island in June 2019.

Figure 1 **Location map showing the Channel Islands and northern France. Areas outlined with a grey dashed line are approximate extents of the larger areas of reefs. Blue dashed line shows extent of Jersey territorial waters.**

1.1 WHAT IS GEODIVERSITY?

The Earth has experienced a rich history of change over geological time, undergoing a wide range of climatic conditions and geological processes that have given rise to the varied materials and landscapes that underpin our environment. The term 'geodiversity' is being increasingly used to identify and highlight the 'natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems' (Gray, 2013).

Geodiversity plays a fundamental role in sustaining biodiversity (e.g., Crofts, 2019; Hjort *et al*., 2015) and in supporting society (e.g., Gray, 2019; Prosser *et al*., 2011). While the term geodiversity typically refers to the diverse *qualities* of the geological environment, the term geoheritage is commonly used to reflect locations, or sites, of particular geological significance (Gray, 2013). Geoheritage sites may reflect important geoscience contexts for understanding Earth history (such as type examples of geological periods, processes or materials), they may illustrate fundamental biotic and abiotic relationships or they may exemplify economic, historical or archaeological associations between people and their environment.

Geoconservation refers to efforts to conserve geodiversity and geoheritage, and it is typically framed in the context of ecological, education, research, tourism and societal benefits. There is growing awareness of the importance of valuing and conserving geodiversity, for practical reasons, such as ensuring sustainable agriculture and industry (e.g., Schrodt *et al.,* 2019), and for cultural benefits and ethical reasons (e.g., Gray, 2019).

1.2 WHY CONSERVE GEOLOGICAL FEATURES?

The importance of conserving geodiversity and geoheritage is increasingly being recognised, leading to local, national and international geoconservation efforts to identify, document and protect geoheritage sites and to promote holistic approaches to environmental management that incorporate the conservation of geodiversity.

The protection of geoheritage and geodiversity provides cultural and economic benefits to society, and it is increasingly being recognised for its importance in conserving biodiversity (e.g., Crofts, 2019), enabling sustainable development (Schrodt *et al.*, 2019) and ensuring resilience to climatic change. This protection is required due to ongoing threats to geodiversity, including the degradation and destruction of important geoheritage sites, the over-exploitation of Earth's resources, the degradation and human modification of landforms and landscapes and the impacts of climatic change (Gray, 2013).

The importance of conserving geological features for education and tourism is highlighted by the published guidelines for UNESCO Geoparks. Ideally, Geoparks should be 'community-led to ensure that an area's geological significance could be conserved and promoted for science, education and culture, in addition to being used as a sustainable economic asset such as through the development of responsible tourism' (UNESCO).

Recognition of the potential impact of damage to and the loss of geodiversity and geoheritage has followed the understanding of the importance and benefits of biodiversity, particularly through the frameworks of 'Natural Capital' and 'Ecosystem Services'. However, while Earth materials and systems have consistently been recognised as core components of 'Natural Capital', their inclusion in the evaluation frameworks of 'Ecosystem Services' has proved to be more controversial (Gray, 2019). Nevertheless, a recent adaption of the 'Ecosystem Services' framework for its application to 'Geosystem Services' (Gray, 2019; Van Ree and van Beukering, 2016) identifies the following component services:

- **Provisioning:** including food, energy and construction and industrial materials
- **Cultural:** including environmental and landscape qualities, tourism, anthropological and historical associations and artistic influences
- **Regulating:** including the role played by the Earth system in regulating climatic, terrestrial and biotic processes, including flooding and water quality

- **Supporting:** including soil processes, natural habitats and space for human activities
- **Knowledge:** recognising the value of the geological system as a record for past Earth environments and processes, and thus seeing that it is critical for developing knowledge and education and monitoring ongoing environmental change

While this framework provides an overarching perspective concerning the value of investing in geoconservation, in practice, on-the-ground geoconservation efforts typically reflect a diverse combination of actions undertaken by community and interest groups, the management priorities and practices of landowners and the planning and regulatory policies of local and national governments. Because the motivations of particular groups for investing in geoconservation may vary, the latter is particularly important for ensuring sustained and systematic efforts to conserve geoheritage and geodiversity.

The recognition of *knowledge* as a key geosystem service has particular significance, as it represents an extension of the 'Ecosystem Services' framework (Gray, 2019). The identification of knowledge as a societal service reflects the importance of the geological record for understanding the nature and dynamics of Earth systems and processes and for reconstructing the history of the planet and the evolution of life, including human life. As Gray (2019) notes, 'an important reason for conserving geoheritage is that it gives us an understanding of the history of the planet and our place in it' (p 232).

Thus, investment in the preservation of geoheritage is necessarily linked to the value of important geological sites for advancing geoscience, ecological and anthropological research; facilitating education; and informing the general public, for example, through geotourism. The value of geoheritage is both local, involving particular landscapes, ecosystems and communities, and global, because it collectively represents the diversity of environments and processes that allow us to understand how the Earth functions at the planetary scale.

This local-to-global perspective is reflected in the network of UNESCO Global Geoparks. The Geoparks represent designated areas 'where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development'[1]. The network currently comprises 161 parks located in 44 countries, spanning diverse landscape types and geological contexts.

1.3 JERSEY'S GEODIVERSITY

In Jersey, a number of natural sites are recognised for the significance of their biological and/or geological qualities through the network of Sites of Special Interest (SSIs). These sites are protected under the Island Plan planning framework.

Twenty-two SSI sites are presently recognised as geological features of interest; they were identified following a review of Jersey's geodiversity by Davis (1996). Overview information on the key sites was provided in the original review.

This new review and audit was commissioned to identify potential additional sites that could be included in an expanded SSI network and to provide a systematic evaluation of and documentation for all geodiversity sites in Jersey. Opportunities to expand the network have been considered in relation to the following contexts:

- ensuring the comprehensive representation of key elements of Jersey's geological history
- improving the understanding of links between geodiversity and historical/archaeological features
- increasing the potential for geotourism.

[1]http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/

The scope of the audit includes a review of the existing Geological SSI sites and the identification of potential new sites. The evaluation of the geodiversity 'value' is undertaken for all identified sites, including the existing SSIs, and forms the basis for the recommendation of potential new sites.

1.4 AIMS AND OBJECTIVES

This study provides a geodiversity audit of Jersey to ensure the comprehensive documentation of the features of key sites of interest and the systematic evaluation of the geodiversity 'value' of the sites.

The audit employs a formal assessment process with the aim of identifying a network of significant sites that provide a comprehensive representation of the diverse geology and geomorphology of the area. To achieve this aim, the objectives of the study are as follows:

1. Undertake a review of existing/known sites of geological/geomorphological significance.
2. Identify additional sites to ensure as full a representation as is practical of the geology and geomorphology of the Island with a broad geographical spread.
3. Recommend site boundaries and, where appropriate, make suggestions for the future management of the site, following the assessment of the current site condition.
4. Establish the geodiversity value for each site, based on a series of criteria including scientific, educational, cultural and community merits.
5. Provide information that will enable the integration of geology with the area's landscape, biodiversity and cultural and economic heritage.
6. Identify key geological sites that may be appropriate for conservation and/or enhancement with respect to education and public enjoyment. Provide information on access and safety aspects for sites and their vulnerabilities and natural hazard risks.

1.5 CONVENTIONS AND SOURCES OF FURTHER INFORMATION

Geological terms

While every effort has been made to explain the geological terms used throughout this report, geology is a technical subject that suffers from its share of jargon. Use should also be made of online resources, such as Wikipedia (https://www.wikipedia.org/), to understand other terms.

Online reports and maps

The BGS also produces a range of free downloadable resources that may be helpful for the reader, including how rocks are classified and described. Of particular relevance to Jersey are the British Geological Survey 'Rock Classification Schemes', which are available via the website www.bgs.ac.uk. Another useful resource is the 'Open Geoscience' section of the website, through which all historical published maps and reports are free to view. This report also includes a reference section, which contains an extensive list of the literature that has been referred to during this study.

Grid references

All grid references used in this report use decimal metres and decimal latitude and longitude. These are with respect to the Jersey Transverse Mercator; the Authority ID is EPSG:3109, and the projection system matches that used by Jersey Heritage.

Conventions used in reporting geological ages

Throughout this report, references are made to the ages of rocks and sediments. For bedrock units, the age is normally expressed in millions of years (Ma).

In Jersey, the ages of most of the main rock units have been determined using methods that date rocks or minerals directly by measuring the isotopes of chemical elements that undergo radioactive decay. These methods produce a numerical value, which is often accompanied by an analytical error range (e.g., 482 ± 1.6 Ma). In Jersey, the most reliable dates have been produced by applying the uranium-lead (U-Pb) isotope dating system to the mineral zircon. The age of zircon crystals in igneous rocks is generally taken to be the age of magma crystallisation, which is essentially coincident with magma emplacement. Zircon does not grow in sedimentary rocks, but zircon grains derived from the erosion of other rocks can be deposited with other grains as the sediment accumulates. The age of the youngest zircon grain in a sedimentary rock is then taken to be the maximum age of sediment deposition.

Age reporting for the Quaternary Period should also be discussed. The most recent geological period, spanning the past 2.6 Ma, can also be confusing, as several conventions are used depending on the period being discussed or in some cases on the dating method used to derive the ages. In this report the authors have maintained the convention of describing those ages prior to the Holocene as abbreviated ages in thousands of years before present (ka BP). For example, an age of 25,000 years will be written 25 ka BP.

For ages from the last *c.* 30,000 years, which are often derived using radiocarbon dating methods, two main conventions exist. If ^{14}C dating has been used, some researchers will report ages in radiocarbon years with an error derived from uncertainty in the measurement process, for example, 10,430 ± 50 ^{14}C yr BP. Unfortunately, due to the non-linear way that ^{14}C degrades over time, radiocarbon years need to be calibrated against known curves to derive an actual age. Therefore, our example of 10,430 ± 50 ^{14}C yr BP yields a calibrated actual age of 12,310 ± 200 cal ^{14}C yr BP. Where published ages are quoted in this report, if the information is available, the authors have included both the ^{14}C age and the calibrated age for clarity.

This report also refers to units of geological time, utilising chronostratigraphic terms. The British Geological Survey and this report follow the conventions set out by the International Commission on Stratigraphy (ICS), whose primary objective is to collate information from the geological community and to precisely define these terms, namely periods, epochs and ages and their subdivisions of systems, series and stages.

Chronostratigraphic terms and their numerical ages are periodically updated as new evidence is presented. The ICS maintain an International Chronostratigraphic Chart, which is freely available via its website (https://stratigraphy.org/chart). Version 2020/01 of this chart has been used for this report.

1.6 STRUCTURE OF THE REPORT

The following report provides an overview of the geological history of Jersey and the wider aspects of Jersey's geoheritage that are related to its human history (Section 2), followed by a description of the methodological steps for the identification and auditing of sites (Section 3).

An overview of the site evaluation is provided in Section 4, with descriptions of recommended sites.

An overview of the context of geoconservation and geodiversity in the UK is provided in Section 5, followed by conclusions and recommendations from the audit (Section 6). The detailed evaluation reports for the audited sites are provided in Sections 7 and 8.

2 Jersey's Geological Heritage

2.1 BEDROCK STORY OF JERSEY

Introduction

The bedrock of Jersey and the other Channel Islands forms part of a region of uplifted sedimentary and igneous rocks that are known as the Armorican Massif, which extends into adjacent areas of France, Spain and the Czech Republic. Reconstructions of the North Atlantic region suggest that rocks that were affected by events of a similar age, prior to the opening of the Atlantic Ocean, are also found in southern Britain and Ireland, Atlantic Canada and the Eastern Seaboard of the USA within the belt of uplifted and deformed ancient strata that geologists call the Appalachian-Caledonian Orogenic Belt (D'Lemos *et al*., 1990; Nance *et al*., 2008).

In the Armorican Massif, the sedimentary, metamorphic and igneous rocks were formed during, and/or were affected by, two major and long-lived geological events: the Cadomian Orogeny and the Variscan Orogeny (also known as the Hercynian Orogeny), which occurred during the Late Devonian to Permian. The Island provides important insights into the geological events and environments that existed at that time.

The Cadomian Orogeny comprised a series of tectonic events that were related to the subduction of an oceanic plate beneath the northern margin of a supercontinent known as Gondwana. During plate subduction, oceanic plate melting caused magmatism and the creation of at least one island arc. Associated with this was the formation of sedimentary basins, and with continued subduction, these basins were eventually accreted onto the continental margin of Gondwana (Figure 2; D'Lemos *et al*., 1990; Nance *et al.,* 2008; Woodcock and Strachan, 2012; Miller *et al*., 2001).

The Cadomian Orogeny is thought to have begun approximately 700 million years ago (Nance and Linnermann, 2008) and Jersey's oldest rocks, the foliated granodiorites of the Écréhous, Minquiers and Paternoster reefs (Figure 1), are thought to have been emplaced and deformed during this orogeny (Chambers *et al*., 2016). Their age is not well constrained but they are thought to be 667–656 million years old (Guerrot and Peucat, 1990). These foliated granodiorites were emplaced into older metamorphic gneisses that are thought to have been deformed during an early phase of the Cadomian Orogeny (Renouf, 1985). One interpretation of these oldest basement gneisses is that they represent equivalents to the Icart Gneiss of Guernsey and equivalent rocks on Sark that were metamorphosed around 2100 million years ago during the Eburnean Orogeny of the adjacent ancient supercontinent of Gondwana (West African Craton; Samson and D'Lemos, 1998).

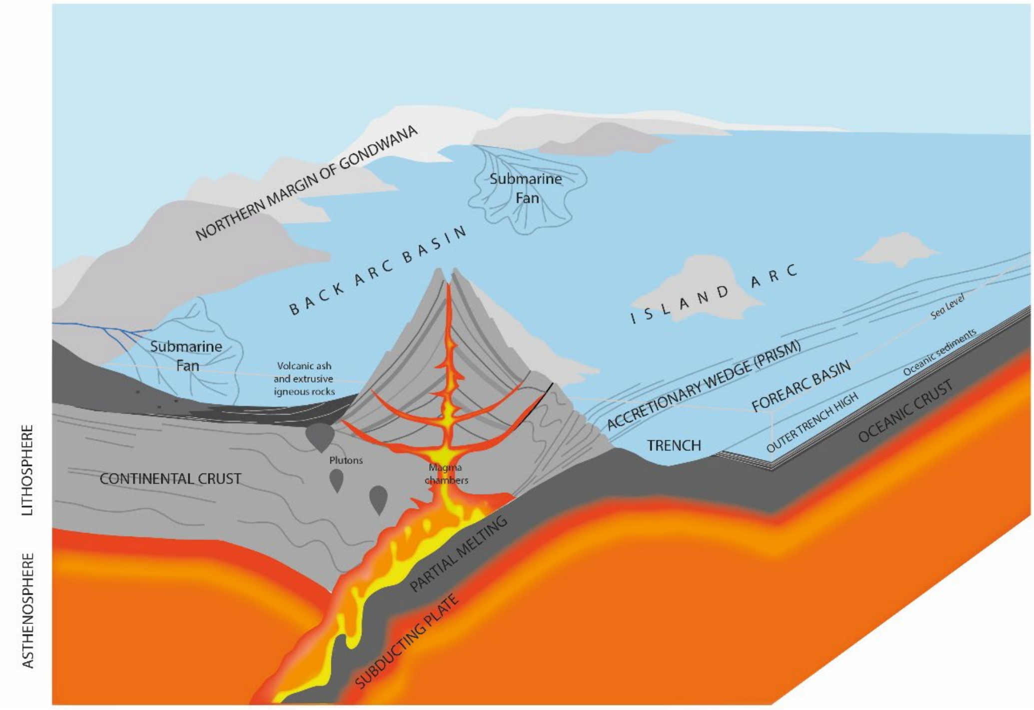


Figure 2 **Conceptual diagram of an island arc.**

The oldest bedrock unit on mainland Jersey is known as the *Jersey Shale Formation* and comprises a thick succession of interlayered sandstone and mudstone that was deposited in a forearc or back-arc marginal basin around 587 million years ago (Miller *et al*., 2001) on the sub-sea flank of an island arc (Figure 2). Sedimentary features preserved in these rocks suggest that the sediments were deposited on one or more submarine fans; the remnants of these fans can be examined in exposures in the western part of Jersey (Helm and Pickering, 1985). These types of deposits are known as turbidites and are the product of turbulent subaqueous flow. Incorporated within the fan sediments are a few thin layers of volcanic ash, suggesting that there was volcanic activity on the adjacent island arc at this time.

Overlying the *Jersey Shale Formation* is a thick succession of calc-alkaline volcanic and volcaniclastic rocks known as the St Saviour's Andesite Formation. The volcanic rocks were sourced from an island arc that, in today's orientation, lay to the north-east and south of Jersey, and they were deposited in the adjacent marginal basin, overlying the *Jersey Shale Formation* (Figure 2).

Two more formations dominated by volcanic and volcaniclastic rocks, known as the St John's Rhyolite Formation and Bouley Rhyolite Formation, overlie the St Saviour's Andesite Formation in north-east Jersey. However, several lines of evidence suggest that the top of the St Saviour's Andesite Formation is an unconformity, marking a hiatus in the accumulation of the volcanic pile. This evidence includes the presence of folding, which is preserved in both the St Saviour's Andesite Formation and *Jersey Shale Formation* but is absent in the overlying volcanic formations (Institute of Geological Sciences, 1982). Additional evidence includes the presence of outcrops of mudstone and conglomerate (the Vicard Mudstone and L'Homme Mort Conglomerate) lying stratigraphically between the St Saviour's Andesite Formation and the overlying St John's Rhyolite and Bouley Rhyolite formations (Bishop and Bisson, 1989). The unconformity also coincides with a change from mainly andesitic lavas (below) to mainly rhyolitic lavas (above), which may indicate that an increasing proportion of continental crust (rather than dominantly oceanic crust) was being melted as subduction continued close to the plate boundary. The period of erosion represented by the unconformity therefore marks a significant change in both tectonic and magmatic character. However, an age of *c.* 583 Ma for a layer of volcanic rocks within the Bouley Rhyolite Formation (Miller *et al.,* 2001) is just a few million years younger than the youngest detrital zircons in the *Jersey Shale Formation*, indicating that both the accumulation of the St Saviour's Andesite Formation and the period of erosion that succeeded it were relatively short-lived.

Rocks of equivalent age to the *Jersey Shale Formation* and the overlying volcanic units are also found in northern France; collectively, these rocks are known as the Brioverian Supergroup (after Cogné, 1972; Barrois, 1899; Graindor, 1957; Cogné, 1959, 1972).

Similar U-Pb ages indicate that the volcanic rocks in Jersey and the intrusive rocks of the *South-west igneous complex* (and therefore probably also the *South-east igneous complex*) formed essentially contemporaneously (Table 1; Miller *et al.,* 2001). However, mapped field relationships (Institute of Geological Sciences, 1982; Figure 3) suggest that the *South-east igneous complex* cuts the volcanic rocks and is therefore slightly younger.

This pulse of magmatism is also recorded elsewhere in the Channel Islands in Guernsey and Sark and is represented by granite with magma-mingled diorite and gabbroic rocks. The close ages of the southern igneous complexes and volcanic rocks across the region suggest that they are intrusive and extrusive equivalents of the same magmatic event (Miller *et al*., 2001; Lees and Roach, 1993).

After a gap of some 100 million years, there was a period of renewed magmatism in the Early Ordovician (*c.* 482 Ma; Miller *et al*., 2001; see also Adams, 1976; Bland, 1985; D'Lemos *et al.,* 1992) that produced the large *North-west igneous complex*, which underlies most of north-west Jersey and may include the igneous rocks at Belle Hougue Point. Although the Cadomian Orogeny is often quoted as ending around 540 Ma, during the Cambrian (e.g., Linnemann *et al.,* 2008), it is possible that the *North-west igneous complex* is a late Cadomian event (for example, Adams, 1976; Bland, 1985); however, some researchers consider this pluton to be unrelated to the Cadomian Orogeny (for example, Miller et al., 2001). More research is needed to understand how this pluton is related to other plutons of a similar age in the region.

The *Rozel Conglomerate Formation* (and equivalent terrestrial sediments elsewhere in the region) may represent molasse deposits formed during or after the uplift associated with the Cadomian Orogeny. These sediments, which consist of very coarse conglomerates with some sandstones and mudstones, were sourced from an area that in today's terms lay to the north of the present outcrop and were deposited as alluvial fans within small extensional or transtensional basins (Went and Andrews, 1990; Went, 2005). The age of the Rozel Conglomerate is not known with certainty, but based on evidence derived from other red bed sequences in the region, with which the Rozel Conglomerate is correlated, an Early Ordovician date is suggested by the French Geological survey; however, McMahon *et al*. (2017) propose an alternative view, suggesting that they were deposited between the latest Ediacaran and earliest Cambrian.

The youngest bedrock units in Jersey are mica-bearing lamprophyre dykes, which are found throughout the Island. The dykes cut all the main bedrock units in Jersey, including the Ordovician-aged *North-west igneous complex*, and they are therefore younger than these bedrock units.

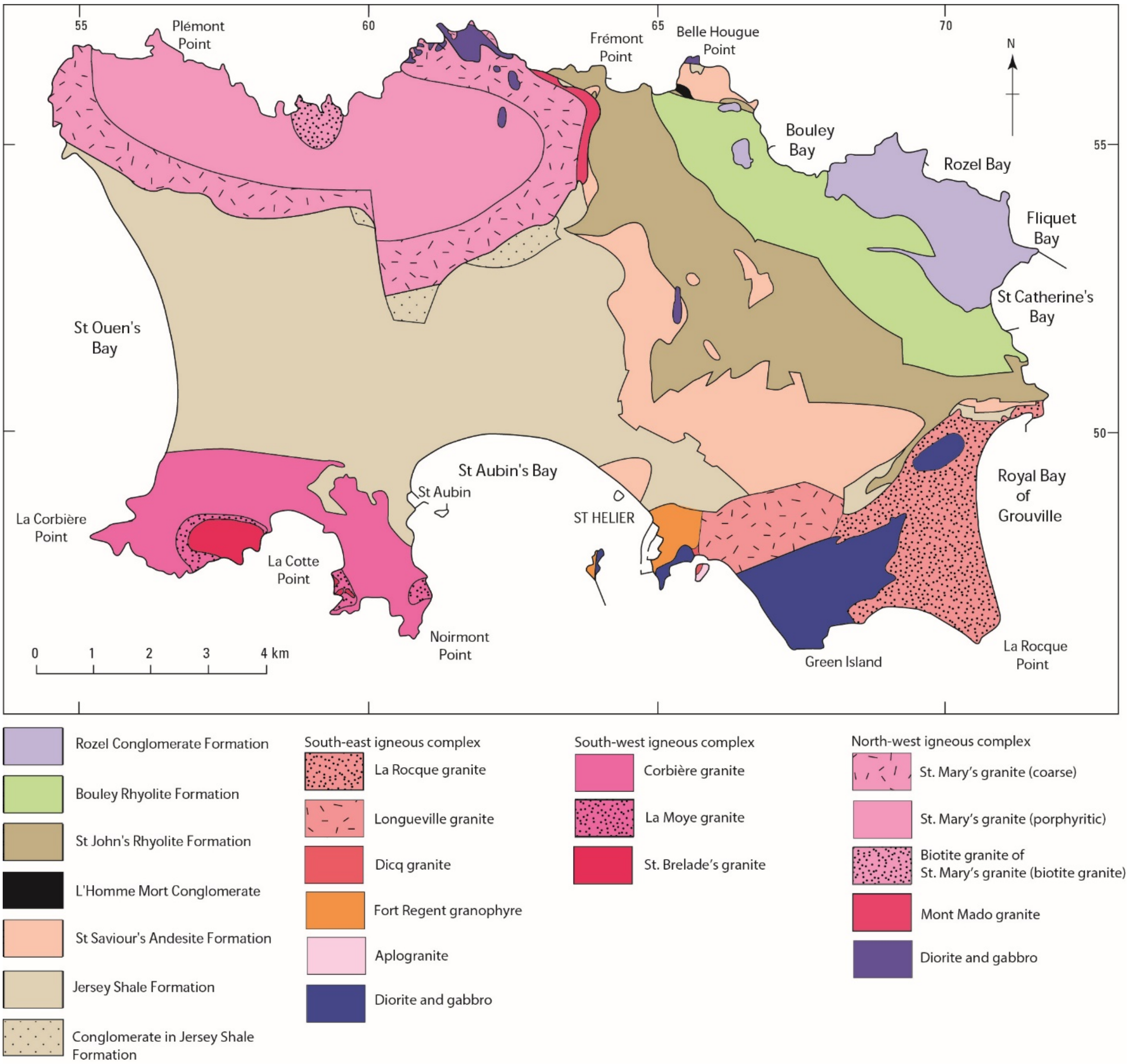


Figure 3 **Geological sketch map showing the bedrock geology of Jersey (after Bishop and Bisson, 1989; Brown *et al.*, 1990).**

Age	Stratigraphic unit	Lithodemic unit	Regional tectonic event	Isotope dates	Notes
Devonian to Permian			Variscan orogeny		
Silurian		Lamprophyre sheets	Accretion of Peri-Gondwanan terranes onto Laurentia, final closure of Iapetus and creation of Laurussia	427 ± Ma (K-Ar hb) dyke cutting *Rozel Conglomerate Formation* (Adams, 1976)	
Upper Cambrian to Ordovician	*Rozel Conglomerate Formation*	Younger basic and acid sheets	Peri-Gondwanan terranes migrate from Gondwana into Iapetus	Contemporaneous with or very slightly younger than *North-west igneous complex*	
		North-west igneous complex (including Bell Hougue igneous complex)		482 ± 1.6 Ma (U-Pb) (Miller *et al.*, 2001)	*Rozel Conglomerate Formation* is correlated with other red beds in the region, which are thought to be this age based on stratigraphic position and trace fossil evidence
Ediacaran (late Precambrian)		Older basic and acid sheets		Contemporaneous with or very slightly younger than South-west and *South-east igneous complexes*	
		South-west igneous complex / *South-east igneous complex*	Island arc activity from subduction of lithosphere and (Andean type) collision at the periphery of Gondwana Supercontinent – Cadomian Orogen	580 +2.3/-1.6 Ma (U-Pb) (Miller *et al.*, 2001) / 563 ± 1 Ma (Ar-Ar) from Le Nez (D'Lemos *et al.*, 1992). Between 583 ± 11 and 527 ± Ma (K-Ar) (Adams, 1976)	Probably contemporaneous
	Bouley Rhyolite Formation			582.8 ± 2.7 Ma (U-Pb) (Miller *et al.*, 2001). Based on Anne Port Rhyolite	Deformation event, postdating St Saviour's Andesite Formation, folds it and older units
	St John's Rhyolite Formation				
	St Saviour's Andesite Formation				
	Jersey Shale Formation			587 Ma (U-Pb) (Miller *et al.*, 2001)	

Table 1 **Jersey bedrock stratigraphy**

2.2 SEDIMENTARY AND VOLCANIC ROCKS

2.2.1 *Jersey Shale Formation*

The *Jersey Shale Formation* is estimated to be 2500 m thick and contains the oldest rocks exposed on the Island of Jersey. They mainly comprise cycles of mudstones, siltstones, sandstones and minor conglomerates, known as turbidites, which have subsequently undergone deformation and low-grade regional metamorphism (Bishop and Bisson, 1989) that is associated with the Cadomian Orogeny and later events.

Turbidites are sedimentary deposits that are genetically related to subaqueous sediment gravity flows in which fluid turbulence is the principal particle support mechanism (also known as turbidity currents). A turbidity current is generated as a result of a contrast between the density of the flow entering the basin (water-sediment mix) and the density of the water within the receiving basin. Turbidity currents can be triggered by earthquakes and storms or they may simply be related to variable fluvial input into bodies of water during climatic fluctuations on land or changes in the relative sea level (marine or even deep lacustrine). They often form as a series of subaqueous fan systems on the basin floor.

Detailed studies of the *Jersey Shale Formation* were made by Helm (1983) and Helm and Pickering (1985), who concluded that the formation represents deposition in a submarine fan on a continental margin. The close association with andesitic volcanic rocks, typical of subduction zone settings, suggests that this basin may have formed in a back-arc or forearc setting (Figure 2). Helm and Pickering identified six sedimentary facies within the *Jersey Shale Formation*, which they grouped into four facies associations. These represent deposition in different regions within the submarine fan: I – canyon or inner fan channel fill, II – middle fan channel fill, III – lower fan / outer fan deposits and IV – outer fan deposits (Figure 4). Helm and Pickering (1985) suggested that the *Jersey Shale Formation* becomes younger to the east and was constructed by northerly directed sediment gravity (turbidity) flows based on palaeocurrent evidence gathered from flute casts and current ripples.

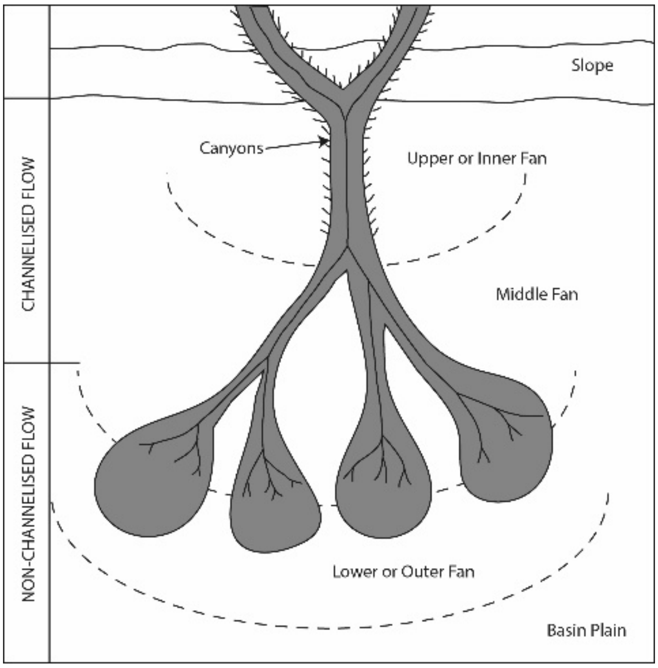


Figure 4 **Idealised components of a submarine fan (after Shanmugam *et al.*, 1985).**

There are a number of identified sites that expose examples of sediments deposited in various parts of the submarine fan. The site at **Petit Étacquerel** has sedimentary features that indicate deposition in shallow ephemeral channels with some interchannel and/or fan-fringing deposits. These features are typical of those found in the lower part of the middle to outer sections of the submarine fan (Association III, Helm and Pickering, 1985). The site at **Grand Étacquerel** provides an opportunity to examine the outer section of this extensive fan (Association IV) and includes lobe, lob-fringe and fan-fringe deposits. The most proximal part of the fan (Association I, Helm and Pickering, 1985) can be examined in small exposures in **St Peter's Valley** near Gargate Mill. The most proximal part of the fan is only seen in very isolated outcrops along the southern margin of the North-west granite complex and comprises disorganised, clast-supported pebble to cobble conglomerates, which are interpreted as debris flows. These kinds of sediments are found in canyon fills or in the inner parts of fans. The most distal part of the sequence is typified by the exposure of the thinly interbedded, graded, fine-grained sequence of sandstones and siltstone turbidites in the south-east corner of the **Giffard Bay** site.

Age of the Jersey Shale Formation

Miller *et al.* (2001) produced a uranium-lead (U-Pb) isotope date for the *Jersey Shale Formation*, based on the dating of detrital zircons. The youngest zircons yielded ages of 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma, providing a maximum depositional age for the unit. They also tested zircons from the overlying volcanic rocks (*Anne Port Rhyolite*), which yielded an age of 582.8 +3/-2.7 Ma, which is interpreted to be the age of eruption. Together, these dates provide good constraints on the age of the *Jersey Shale Formation*.

Regional context

The *Jersey Shale Formation* is part of the Brioverian Supergroup, which includes rocks exposed in the Baie de St Brieuc and La Manche regions of France (e.g., Graindor, 1957; Dupret *et al*., 1990; Guerrot *et al*., 1989).

2.2.2 *Jersey Volcanic Group*

The deposition of the *Jersey Shale Formation* was followed by a period of island arc volcanism and the eruption of a thick succession (over 2200 m thick) of volcanic and volcaniclastic rocks, which in Jersey are known as the *Jersey Volcanic Group* (Bishop and Bisson, 1989; Thomas, 1977).

The *Jersey Volcanic Group* is divided into three formations: the St Saviour's Andesite (oldest), St John's Rhyolite and Bouley Rhyolite (youngest) formations.

The St Saviour's Andesite Formation mainly comprises plagioclase-phyric andesite lava flows, with subordinate basalt, lapilli tuffs and agglomerates. The formation also includes volcaniclastic deposits, such as debris flows, as well as rhyolitic flows and intrusive sheets. In a rare inland exposure of the St Saviour's Andesite Formation at **Mont Sohier**, the lavas contain possible pillow-like structures, lending weight to the argument that these rocks were erupted into a body of water.

The St John's and Bouley Rhyolite formations comprise rhyolitic lava flows and domes, as well as ash flow and scattered debris flow tuff deposits. The St John's Rhyolite Formation is exposed at **Bonne Nuit**, where a wide range of igneous textures and contacts can be examined. Banded rhyolites and tuffs of the Bouley Rhyolite Formation can be readily examined at **L'Islet** and **Bouley Bay**, with the autobrecciated flow-banded rhyolite also being used as the capstone at **Dolmen de Faldouet.** The Bouley Rhyolite Formation is also exposed at **Les Hurets**, where it comprises a sequence of rhyolite lavas and ignimbritic tuffs; of particular interest at this site are fallen blocks containing impressive examples of spherulite devitrification structures.

There have been a number of significant studies on the *Jersey Volcanic Group* that have led to markedly different interpretations of the nature and eruptive setting of these calc-alkaline volcanic rocks. For example, Mourant (1933) claimed that a large portion of the St John's and Bouley Rhyolite formations is composed of rhyolite lava flows. In contrast, Thomas (1977) interpreted the same sequence as being dominated by subaerially deposited ash flows. A later study by Lees and Roach (1993), however, concluded that the *Jersey Volcanic Group* comprises a suite of coeval magmas of basic-intermediate and acid compositions that were erupted in a subaqueous environment. The volcanic rocks in Jersey, irrespective of whether they are interpreted to be lava flows or ash flow tuffs, are often highly welded. Furthermore, debris flow deposits containing clasts of basic to acidic igneous rocks, pyroclastic ejecta and clasts of *Jersey Shale Formation* rocks have been recognised throughout the *Jersey Volcanic Group*. Although the outcrop is disrupted by faulting, **Giffard Bay** provides an opportunity to examine a large part of the volcanic sequence assigned to the St Saviour's Andesite, St John's Rhyolite and Bouley Rhyolite formations.

Age of the Jersey Volcanic Group

The timing of volcanism in Jersey is provided by a uranium-lead (U-Pb) isotopic age of 582.8 ± 3 Ma obtained from zircon in a massive, flow-banded and columnar-jointed rhyolite flow, locally known as the Anne Port Rhyolite and exposed at **Anne Port** (Miller *et al*., 2001). This rhyolite forms the lower part of the *Bouley Rhyolite Formation* and provides an estimate of the age of the eruption of this formation. The *Bouley Rhyolite Formation* is the stratigraphically highest formation within the *Jersey Volcanic Group* and therefore the dated rhyolite provides a potential minimum age for the whole sequence. The maximum age is provided by the youngest concordant zircons from the underlying *Jersey Shale Formation*, dated at 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma (Miller *et al*., 2001).

Regional context

Although the Cadomian orogenic belt of western France and the Channel Islands has an abundance of calc-alkaline plutonic rocks, their extrusive equivalents are relatively rare. These extrusive rocks include the Tufs de Tréguier and Ignimbrites des Lêzardrieux, which occur along the southern boundary of the North Trégor batholith (Auvray, 1989), and the Serie volcano-sedimentaire et complexe ignimbritique de St Germain-le-Gaillard in Normandy (Graindor, 1957; Graindor *et al*., 1976; Lees and Roach, 1993). Consequently, the *Jersey Volcanic Group* in Jersey is important, as it provides one of only a few well-exposed examples of a calc-alkaline volcanic centre within the Cadomian orogenic belt of the Armorican Massif (Bishop and Bisson, 1989; Lees and Roach, 1993).

2.2.3 *Rozel Conglomerate Formation*

The youngest sedimentary rocks exposed in Jersey are those of the *Rozel Conglomerate Formation*, which comprises coarse conglomerates with subordinate sandstones and mudstones. The distribution of this formation is mainly restricted to the north-east of Jersey, with two small outliers west of this main crop exposed at Les Hurets Valley and near Vicard Point.

The *Rozel Conglomerate Formation* is interpreted to have been formed as a succession of alluvial fan deposits, with a source area to the north of Jersey; it is the product of the erosion of the hills created by the Cadomian Orogeny. These sediments provide a great example of the deposits of a river or rivers that developed before the existence of land plants. It is suggested that the evolution of plants and the associated soil development had a profound impact on the morphology of later river systems.

Exposures of the *Rozel Conglomerate Formation* are common along the north-east coast of Jersey. At **La Tête des Hougues**, the *Rozel Conglomerate Formation* unconformably overlies the *Bouley Rhyolite Formation* with an irregular surface marked by a breccia deposit. This unconformity is a regional feature, which can be traced through Alderney and northern Brittany. In these outcrops the unconformity is often a deeply eroded surface with overlying breccias and conglomerates. At **La Tête des Hougues**, the base of the formation comprises a 4 m upwards-coarsening succession of silty mudstones and fine pebble conglomerates overlain by a 3-m-deep, conglomerate-filled channel. These are in turn overlain by a 28-m-thick sequence of upwards-fining coarse debris flows and stream-flood conglomerates. Two main units are identified here: a lower prograding fan of reworked material and an upper unit that is thought to indicate the avulsion and gradual abandonment of a fan lobe. The *Rozel Conglomerate Formation* is also exposed at **Fliquet**, where its eroded top surface preserves more recent peat deposits.

At **Rue de la Solitude**, a weathered conglomerate with sandstone lenses is thought to represent an ancient weathered surface on an abandoned segment of an alluvial fan. The bands of mudstone seen here are thought to be the deposits of a marginal lake, which are rare throughout the rest of the formation (Went, 2005). At **Fliquet**, the conglomerate is exposed on the wave-cut platform on the foreshore; there are preserved rounded cobbles of Jersey Shale and volcanic rocks from the *Jersey Volcanic Group* incorporated within the conglomerate here. It also contains clasts of granite, including types not seen within the granite outcrops in Jersey. Thin, discontinuous bands of sandstone are also present, perhaps indicating periodic deposition in a lower energy environment.

Age of the Rozel Conglomerate Formation

The *Rozel Conglomerate Formation* is the youngest of the sedimentary rock formations in Jersey (Bishop and Bisson, 1989). Many ages have been proposed; they range from the late Precambrian to Early Ordovician. These dates are based on several lines of evidence, including a study on the oldest magnetism acquired through the authigenesis of hematite in mudstones (Duff, 1979) and a possible palaeontological indication of age by Bland (1984), who interpreted trace fossils as impressions of the *Arumberia* {Glaessner & Walter}, a form that is thought to be Ediacaran (late Precambrian) to early Cambrian in age. Went and Andrews (1990) suggest that the *Rozel Conglomerate Formation* was probably deposited in the later stages of the Cadomian Orogeny. Adams (1976) gave a date of 427 ± 13 Ma based on K-Ar hornblende (recalculated as 435 ± 13 Ma) for a dyke that intrudes conglomerates at La Coupe Point, which provides a minimum age of mid-Silurian (Telychian) for the *Rozel Conglomerate Formation*. However, Miller *et al*. (2001) link the deposition of the *Rozel Conglomerate Formation* in minor extensional basins to plutonism dated, using U-Pb, to *c.* 480 Ma (Early Ordovician). Based on evidence derived from other red bed sequences in the region, with which the Rozel Conglomerate is correlated, an Early Ordovician date is suggested by the French Geological survey; however, McMahon *et al.* (2017) propose an alternative view, suggesting that these sediments were deposited between the latest Ediacaran and earliest Cambrian. More work is needed to confirm the age of the Rozel Conglomerate.

Regional and stratigraphic context

Weathered profiles through igneous basement rocks occur beneath Lower Palaeozoic terrestrial sequences in Alderney (Alderney Sandstone Formation), Jersey (*Rozel Conglomerate Formation*) and northern Brittany (Erquy-Fréhel Group). These are all thought to have developed in response to the uplift and subaerial exposure of the Cadomian mountain belt (Went, 1991).

2.2.4 Tectonic structures in the sedimentary rocks of Jersey

Jersey Shale Formation

The tectonic structures in the *Jersey Shale Formation* are best seen in the intertidal reefs in St Ouen's Bay, where Helm (1983) recognised two main phases of deformation, D_1 and D_2 (Figure 5). The earliest folds (D_1) are of two types: simpler, singly plunging folds and periclinal folds. The periclines have a NWN–ESE through N–S to NE–SW trend, are generally asymmetrical, open to close and have a westerly vergence, although some are upright and have a more easterly vergence. Helm (1983) thought that the D_1 periclines represented early-forming buckles initiated by irregularities in bedding and possibly channel structures.

The *Jersey Shale Formation* is deformed into structures that range from gentle, open folds to tight and sometimes isoclinal structures. They are commonly asymmetrical with a z-shape profile and have a gentle to moderate plunge towards the south-west and a dextral vergence. These folds sometimes have a relatively strong, spaced, axial-planar cleavage. Helm (1983) suggested that these simpler folds are parasitic on the eastern limb of the D_1 anticline.

Overall, the bedding of the *Jersey Shale Formation* dips towards the east. Deviations from this pattern are caused by a major D_1 fold known as the St Peter Syncline and an anticline about 1 km further to the east.

The D_1 folds are later modified by N–S compression (D_2), which produced major folds, a non-penetrative axial-planar fabric (S_2) and a system of conjugate shear faults. The D_2 St Ouen's anticline is outlined by the changing strike of the bedding, which changes from NW–SE west of Le Pulec to N–S and then NE–SW further south. Helm (1983) also noticed that both the D_1 and D_2 folds have been overprinted by late radial fractures, which he attributed to the vertical stress caused by the emplacement of the basaltic magma. He also thought that the occurrence of closely spaced N–S joints might indicate yet another, fourth deformation and noted that a similar fabric exists in the adjacent North-west granite complex. Helm (1983) considered dating the periods of deformation difficult but thought that they were likely to be Cadomian in age and may have been modified during the Variscan and Alpine orogenies.

Jersey Volcanic Group

Thomas (1977), and later, Helm (1984), recognised folds of three orientations (E–W, N–S and NE–SW) in the *Jersey Volcanic Group*. Within the St Saviour's Andesite Formation at West Park, the St Helier Syncline plunges to the south-west and has been intruded by granophyre of the *South-west igneous complex*, with cross-cutting relationships. The north-eastward-plunging Trinity Syncline in north-east Jersey affects both the *Jersey Shale Formation* and the volcanic rocks but is modified by small folds that trend E–W or N–S. These smaller folds have produced domes and basins that brought andesite to the surface, for example, north-west of Le Grés and the valley to the south. Helm (1984) recognised a fold pair near Frémont Point, a syncline at Bonne Nuit Bay, E–W folds north of Archirondel Tower and a refolded and faulted syncline in Vallee des Vaux as D_1 structures. D_2 structures include anticlinal flexures that give rise to the inliers of the *Jersey Shale Formation* at Le Bourg and Gorey (the St Saviour Anticline; Figure 5).

Rozel Conglomerate Formation

At the base of the *Rozel Conglomerate Formation* is an unconformity, a palaeotopographic surface that has been folded into an open syncline (D_3), which has a sinuous axial trance that trends NWN–ESE. Variations in this trend suggest that the main syncline is deformed by NE–SW-trending D_4 folds (Figure 5). At La Tête des Hougues, the purple laminated mud rocks at the base of the sequence have a slatey cleavage that strikes 138° and dips moderately steeply towards the north-east. Elsewhere, there is a SE-trending, sub-vertical fabric that flattens and rotates pebbles. This fabric is particularly well developed at St Catherine's breakwater, where it strikes 120° (Helm, 1984).

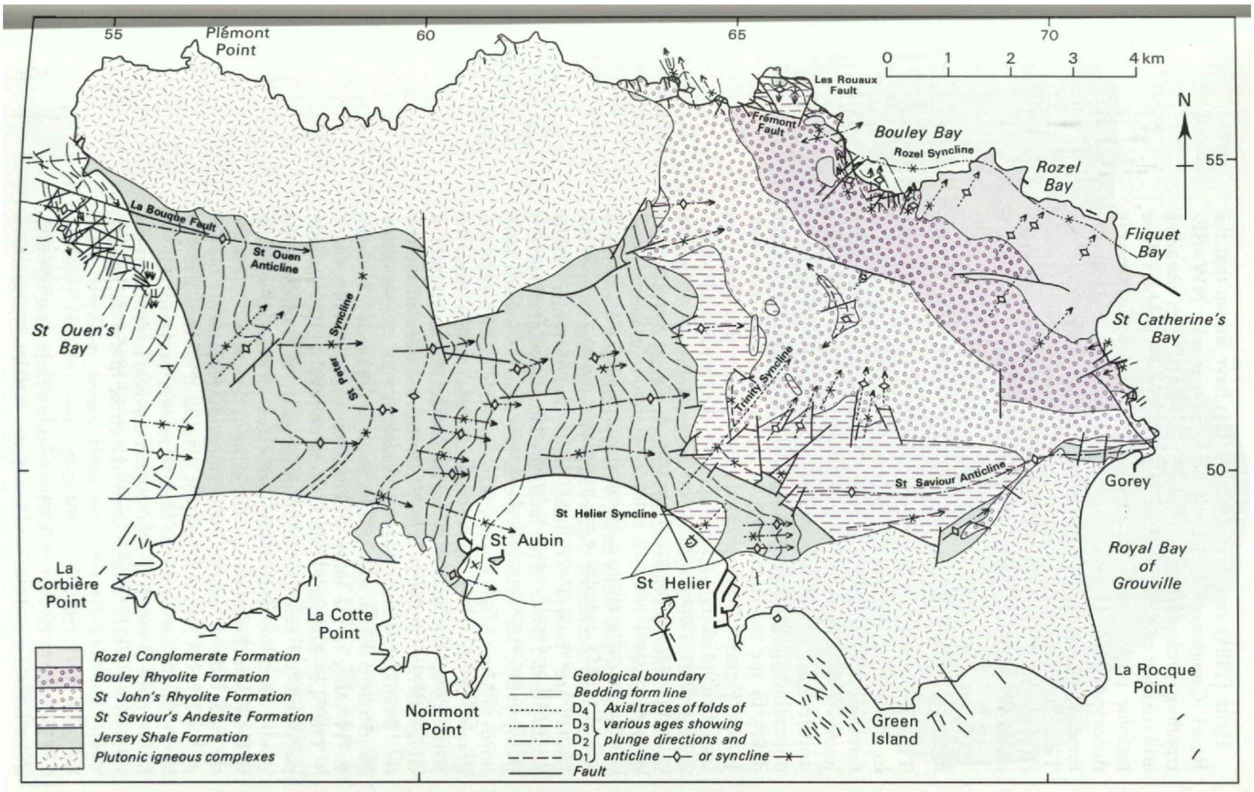


Figure 5 **Sketch map showing the main structural features of Jersey. Based on Helm (1984) and Bisson (1989).**

2.3 INTRUSIVE IGNEOUS ROCKS

2.3.1 Major intrusions

Three major igneous 'complexes' are recognised in Jersey: the *South-east igneous complex*, *South-west igneous complex* and *North-west igneous complex* (Figure 3). Much smaller outcrops of plutonic rocks occur at Belle Hougue Point (*Belle Hougue igneous complex*) and to the east of Becquet Vincent, where a poorly exposed, unnamed mass of diorite has been mapped (Bishop and Bisson, 1989).

South-west igneous complex

The *South-west igneous complex* has three main components that apparently are distributed in a concentric or 'bullseye' pattern (IGS, 1982): *Corbière granite*, which is by far the most extensive, forms around 80% of the onshore outcrop and forms the outer zone; *La Moye granite*, which underlies a narrow belt roughly 250 m wide and forms the middle zone; and *St Brelade's granite*, which forms the small central zone. This pattern indicates that the *South-west igneous complex* is a single, concentrically zoned pluton, and in this respect, it is similar to the *North-west igneous complex* and distinct from the *South-east igneous complex*. The pluton apparently consists almost entirely of granite (no mappable occurrences of mafic rock or rocks formed by the mingling of basic and siliceous magmas have been recorded), and in this respect it differs from both the *North-west igneous complex* and the *South-east igneous complex*. All of the main components of the *South-west igneous complex* are well exposed in extensive outcrops along the south-west coast of Jersey; the outcrops at **Noirmont** and **Beauport** in particular provide typical and readily accessible examples of *Corbière granite* and *Beauport granite*, respectively.

The geometry of the bullseye pattern suggests that around half of the outcrop of the *South-west igneous complex* is on mainland Jersey, with the other half occurring offshore; on this basis, the outcrop of the whole pluton would be around 8 x 5 km. However, granitic rocks crop out on the seafloor for a considerable distance to the south of the south-west Jersey coast (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the south of the *South-west igneous complex* (Figure 6). The offshore outcrop of intrusive igneous rocks actually extends unbroken along the entire south coast of Jersey, suggesting that the *South-west igneous complex* and *South-east igneous complex* are part of the same large outcrop of intrusive igneous rocks (Figure 6).

A U-Pb zircon age of *c.* 580 Ma for a sample of *Corbière granite* from a disused quarry north of La Cotte, on the east side of Ouaisné (Miller *et al*., 2001), confirms that the *South-west igneous complex* was emplaced during the Ediacaran Period, during the Cadomian Orogeny.

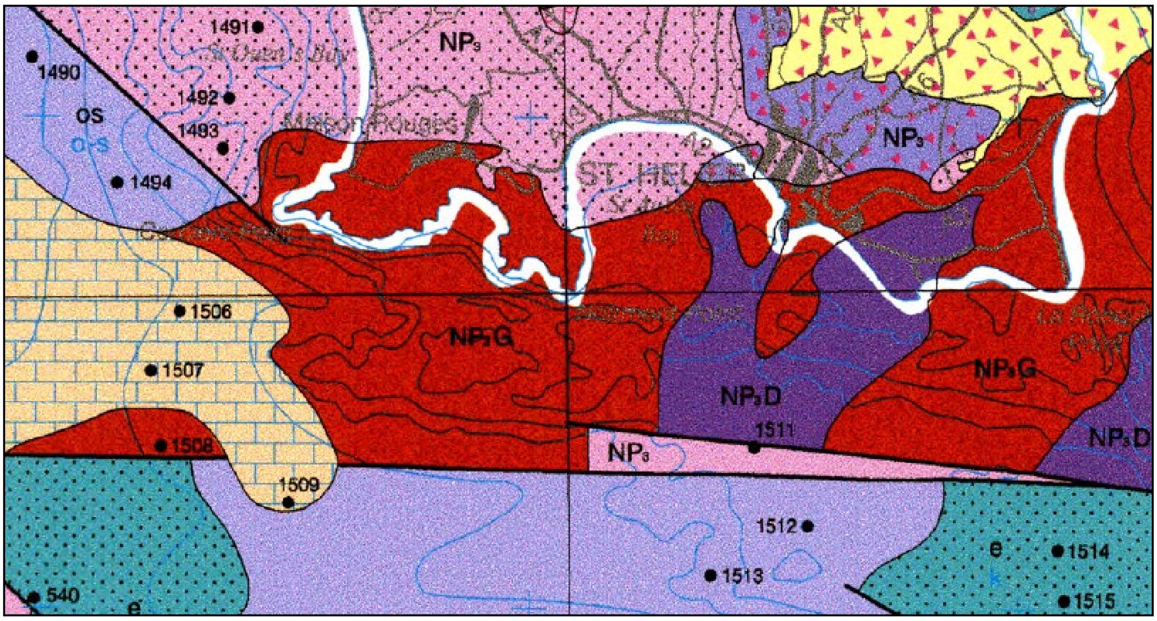


Figure 6 **Map of onshore and offshore bedrock geology around the southern half of Jersey (coastline in white) showing the apparent offshore continuation of the *South-west igneous complex* and *South-east igneous complex*. From BGS (2000).**

South-east igneous complex

Several lithologically distinct components have been mapped within the *South-east igneous complex* (Figure 1), including large (km-scale) masses of basic rock ('diorite and gabbro') and three main variants of granite (IGS, 1982).

Dark grey diorite, grading locally to gabbro, is the oldest component of the *South-east igneous complex*, forming several discrete, km-scale outcrops. The largest outcrop underlies the intertidal reef off La Grève d'Azette and extends inland as far as Grouville; another substantial (km-scale) mass forms a cluster of skerries to the south of Seymour Tower, at the south-east extremity of the extensive reef lying south of La Rocque. Primary igneous layering in diorite and gabbro is preserved in several intertidal exposures, including exposures near La Grève d'Azette, at Le Nez (part of the **La Motte, Le Nez and Le Croc** site) and in the reefs south of Seymour Tower. The consistent orientation of the layering, which generally dips towards the north-east at around 60–70^0 (*c.* 30^0 near Seymour Tower), suggests that these widely separated outcrops were once part of the same large body of layered rocks, which was perhaps the earliest expression of the *South-east igneous complex*. Evidence for a dynamic magma environment, in the form of intimately associated, broadly contemporaneous but compositionally distinct basic, intermediate and siliceous rocks, is displayed in several localities. Notable examples include the exposures between Le Croc and La Motte at Havre des Pas Pier (within the **Dicq to Havre des Pas** site) and at Elizabeth Castle, where the siliceous component is part of a km-scale mass sometimes referred to as the *Fort Regent Granophyre* (e.g., Bishop *et al*., 2003). Early bodies of layered rocks may have been tilted and dismembered when large masses of granite magma (forming the three main granite variants of the *South-east igneous complex*) were subsequently emplaced.

The strongly porphyritic *Dicq granite* is the least extensive of the three mapped variants of granite in the *South-east igneous complex*; its outcrop is restricted mainly to a portion of the intertidal zone south of Grande d'Azette and near Havre des Pas (within the **Dicq to Havre des Pas** site), where the magma has cut and locally mingled with early dioritic rock. A further small (*c.* 100 x 100 m) outcrop of *Dicq granite* is mapped *c.* 1.2 km north-east of Le Dicq. The essentially non-porphyritic *Longueville granite* underlies a significantly larger area of ground, beneath the south-east part of St Helier and to the north of the largest body of dioritic rock; however, exposure is very poor over most of the outcrop. *Longueville granite* and *Dicq granite* are probably broadly contemporaneous (see the description for the **Dicq to Havre des Pas** site). *La Rocque granite* (called 'Le Hocq granite' by Lees [1986] and 'Le Hocq–La Rocque–Gorey granite' in Bishop *et al.* [2003]) is by far the most extensive granite component of the *South-east igneous complex*, at least onshore. It forms much of the intertidal reef in St Clement's Bay, part of which is within the **La Rocque** site, and crops out on the mainland north of there, as far as Mont Orgueil. Cross-cutting relationships with dykes in the *Jersey Main Dyke Swarm*, well displayed in intertidal exposures near La Grève d'Azette, indicate that *La Rocque granite* is also the youngest of the main granite components in the *South-east igneous complex* (IGS, 1982).

Unlike the other two large intrusion complexes in Jersey, the main components of the *South-east igneous complex* are not arranged in a pattern of concentric zones, but instead form irregularly distributed, irregularly shaped, discrete, km-scale masses dominated by either diorite and gabbro or granite (IGS, 1982). The onshore outcrop of the *South-east igneous complex* (including the intertidal reefs) is at least 10 x 7 km in extent. However, granitic and dioritic rocks crop out on the seafloor for a considerable distance to the south, west and east of the south-east Jersey coast (BGS, 2000), suggesting that the onshore outcrop of the *South-east igneous complex* is just a small part of a much larger intrusive complex (Figure 6). Indeed, the offshore outcrop of intrusive igneous rocks extends unbroken along the entire south coast of Jersey, suggesting that the *South-west igneous complex* and *South-east igneous complex* are part of the same large outcrop of intrusive igneous rocks (Figure 6).

Unlike the other two main intrusion complexes in Jersey, a U-Pb zircon age has not been reported for the *South-east igneous complex*. Instead, a range of ages between *c.* 583 and 527 Ma has been reported; they are based on K-Ar isotopic dating (Adams, 1967; D'Lemos *et al*., 1992). The K-Ar system is prone to resetting during rock alteration events, so generally it does not produce accurate dates for the crystallisation of coarse-grained igneous rocks; consequently, the results should not be compared directly with U-Pb zircon ages. Similarities in the characteristics of cross-cutting dykes (*Jersey Main Dyke Swarm*), and the fact that intrusive plutonic rocks form an unbroken outcrop offshore between the south-west and south-east extremities of Jersey (Figure 6), suggest that the *South-west igneous complex* and *South-east igneous complex* are broadly contemporaneous. On this basis, the *South-east igneous complex* was probably emplaced during the Ediacaran Period, during the Cadomian Orogeny.

North-west igneous complex

Two main components of the *North-west igneous complex* were distinguished on the geological map of Jersey (IGS, 1982) – *St Mary's granite*, which forms more than 90% of the onshore outcrop, and *Mont Mado granite*, which underlies a sliver of ground at the eastern extremity of the outcrop. Subsequently, the outcrop of *St Mary's granite* has been divided into several components distinguished by their textural and/or mineralogical characteristics. The following zones are distributed in a concentric or 'bullseye' pattern (Figure 3): an outer zone of 'coarse granite', a middle zone of 'porphyritic granite' and a small central zone of 'biotite microgranite' (Bland, 1985; Brown *et al*., 1990). This pattern suggests that the *North-west igneous complex* is a single concentrically zoned pluton. Most of the pluton has a granite composition, but 100-m-to-1-km-scale bodies made of diorite, gabbro and lithologically heterogeneous rocks, formed through the mingling of basic and siliceous magmas, crop out discontinuously within a swathe of ground roughly 2 km wide that extends from St John's Village to the coast around Sorel Point. Extensive outcrops along the north-west coast of Jersey present excellent examples of all the main components of the *North-west igneous complex*; the outcrops within the sites at **Le Pinacle** and **Le Pulec** provide accessible examples of rocks forming the outer zone of *St Mary's granite*, while those within the **Sorel Point** site provide superb examples of rocks formed through the interactions of siliceous and basic magmas.

The geometry of the bullseye pattern suggests that most of the outcrop of the *North-west igneous complex* is on mainland Jersey, with only about one quarter of the pluton lying offshore. On this basis, the outcrop of the whole pluton would be around 10 x 6 km. However, granitic rocks crop out on the seafloor for a considerable distance to the north and west of north-west Jersey (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the north of the *North-west igneous complex* (Figure 7).

A U-Pb zircon age of *c.* 483 Ma for a sample of *St Mary's granite* from the **Mont Huelin Quarry** (Miller *et al.,* 2001), in the outermost zone of the pluton, suggests that the *North-west igneous complex* was emplaced in the Ordovician Period. As such, it is around 100 million years younger than the other two main igneous complexes in Jersey (the *South-west igneous complex* and *South-east igneous complex*). The cause of the magmatism that produced the *North-west igneous complex* is not clear, but it may represent a late Cadomian event (e.g., Adams, 1976; Bland, 1985). Other researchers consider it to be linked to a later, post-Cadomian event (e.g., Miller et al., 2001), like the widespread tectonic features associated with the opening of the Rheic ocean realm at this time. More research is needed to better understand the origin of this pluton.

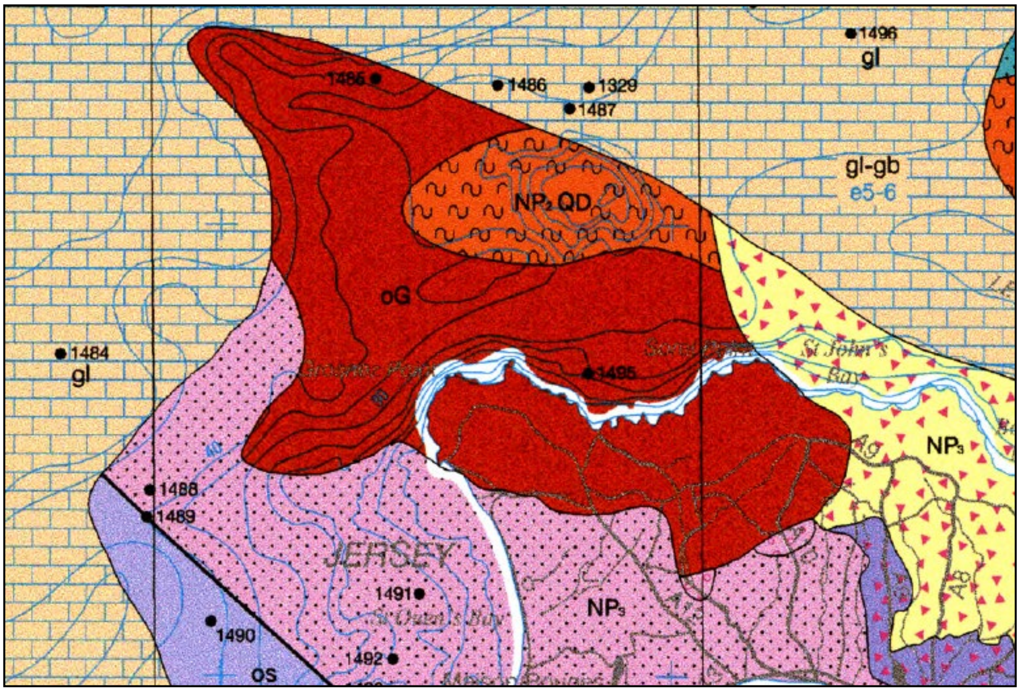


Figure 7 **Map of onshore and offshore bedrock geology around north-west Jersey (coastline in white) showing the apparent offshore continuation of the *North-west igneous complex*. From BGS (2000).**

A small outcrop of diorite and granite (the latter described as being 'syenitic' locally) at Belle Hougue Point has been referred to previously as the *Belle Hougue igneous complex* (IGS, 1982). The rocks here have not been dated directly, but close proximity to the eastern part of the *North-west igneous complex* and broad lithological similarities with the rocks there suggest that the *North-west igneous complex* and *Belle Hougue igneous complex* are related.

2.3.2 Minor intrusions

Two distinct generations of sheet intrusions crop out in Jersey. The older generation, known as the *Jersey Main Dyke Swarm*, is dominated by dykes of basic to intermediate composition, although dykes of siliceous composition (microgranite and rhyolite) are also present. A younger generation, referred to here as 'late lamprophyre dykes', consists predominantly of mica lamprophyre.

Jersey Main Dyke Swarm

The *Jersey Main Dyke Swarm* is the name assigned by Lees (1986) to the obvious concentration of dykes that crop out within the E–W-trending area of ground underlain by the two main igneous complexes in south Jersey. The dykes typically are steeply dipping, and most are less than 1 m wide; good coastal exposures reveal that they can account for around 10% of the outcrop locally. The swarm is particularly well exposed, and particularly abundant, in the extensive intertidal reef to the west and east of Le Croc in south-east Jersey.

The dykes display strong preferred orientations: E–W in the *South-west igneous complex* (e.g., within the **Noirmont** site) and NE–SW in the *South-east igneous complex* (as seen in the **Dicq to Havre des Pas** site). A small proportion of dykes have a broadly N–S trend; these dykes must have opened in a stress regime different from that of the dykes forming the main part of the swarm, indicating that the swarm as a whole has a multistage emplacement history.

Dykes of basic (i.e., basalt and dolerite) composition predominate, but Lees (1986) noted that the dykes cutting the *South-west igneous complex* are mainly dolerite, whereas those cutting the *South-east igneous complex* display a broader range of compositions, including dolerite, microdiorite, lamprophyre and rhyolite (or microgranite). Where they occur together, for example, in exposures on the foreshore at Mont Orgueil, the basic (doleritic) dykes often cut the siliceous dykes. Many dykes are porphyritic; small phenocrysts of plagioclase and ferromagnesian minerals predominate in dykes of basic composition, while phenocrysts of quartz and feldspar occur in siliceous examples. Some dykes are composite, containing both basic and siliceous components; in such cases, basic margins and siliceous centres are common.

The dykes were emplaced during and shortly after the later stages of assembly of the two main igneous complexes in south Jersey (Lees, 1986). Based on whole-rock chemical analyses, Lees (1986) described the swarm as having a calc-alkaline character of a potassium-rich ('high-K') type 'characteristic of basalts generated at an active continental margin'.

Dykes of similar lithologies, and often with similar trends, occur in other parts of Jersey, although they are relatively rare; many are probably genetically related to the *Jersey Main Dyke Swarm*.

Late lamprophyre dykes

Lamprophyre is a relatively rare form of igneous rock that crystallises from small batches of ultrapotassic magma sourced directly from the mantle. Hornblende-bearing lamprophyre is a minor component of the *Jersey Main Dyke Swarm* (and contemporaneous intrusions that are technically not part of the swarm). Younger dykes of mica-bearing lamprophyre are much more common and have been recorded in many parts of Jersey (e.g., Smith, 1933, 1935); a good example is contained within the **Noirmont** site. Most are less than 2 m thick (occasionally they reach 3 m), subvertical and broadly N–S trending (mainly in the sector between NNW–SSE and NNE–SSW). These late lamprophyre dykes have not been dated but have been observed cutting all the main bedrock units in Jersey, including the *North-west igneous complex* and the *Rozel Conglomerate Formation*. They appear therefore to be the youngest bedrock features in Jersey, and they may be related to the Variscan (also known as Hercynian) Orogeny, which produced abundant magmatism in south-west England and in the Armorican terrane of north-west France during the Devonian and Carboniferous periods. Thin sections of the Jersey examples typically reveal phenocrysts of olivine (always pseudomorphed by carbonate and serpentine), pyroxene and mica (biotite) in a fine-grained and variably altered groundmass of alkali feldspar, ferromagnesian silicate minerals and opaque oxide (e.g., Smith, 1935; Bishop and Bisson, 1989); lamprophyres with this mineral composition are called minettes.

2.4 UNCONFORMITY

The youngest bedrock unit exposed in Jersey is the Rozel Conglomerate, which is likely to be lower Palaeozoic in age. The next youngest sediments found in Jersey are Quaternary in age, deposited after a time gap of more than 500 million years. During this time gap, two significant mountain building events occurred – the Variscan and Alpine orogenies, which have helped to shape the landscape and geology of Jersey.

The Variscan Orogeny occurred between the late Devonian and early Permian. This orogeny was the result of the complex, staged collision between two large palaeo-supercontinents called Laurasia and Gondwana, which resulted in the closure of an ancient ocean called the Rheic Ocean and the generation of a new supercontinent called Pangaea. The absence of any deposits of Permian or Triassic age suggests that during this interval, Jersey formed part of the landmass of Pangaea, and terrestrial conditions occurred that restricted sediment deposition and preservation; alternatively, rocks of this age may have been eroded away. Later, during the Jurassic and Cretaceous, there was a period of regional crustal subsidence and basin development with widespread marine conditions occurring across much of the UK and eastern France, including the deposition of Cretaceous-aged rock offshore. However, the onshore absence of Jurassic and Cretaceous rocks implies that Jersey and neighbouring Brittany may have been land during this interval or that rocks have been removed by subsequent erosion.

Towards the end of the Cretaceous and continuing through the Cenozoic, north-west Europe has been affected by a second period of mountain building, corresponding to the Alpine Orogeny. The Alpine Orogeny occurred due to the close of the Tethys Ocean (the present-day Mediterranean being a relic of this basin) and subsequent collision between the Eurasian, African and Iberian plates. Across north-west Europe, many of the Mesozoic basins, including several in southern England and north-east France, underwent uplift and inversion during the Palaeocene and Eocene. A second phase of regional uplift occurred during the Oligocene and Miocene, but since then, the magnitude of northwards-directed crustal compression has waned. Instead, vertical crustal motion has been largely driven by erosion isostasy: crustal mass is eroded from continental interiors (resulting in uplift) and transferred to basins (causing loading and subsidence). A striking feature of the Alpine Orogeny is the amount of crustal exhumation, which in some former inverted Mesozoic basins exceeds 1.5 km. While the amount of Cenozoic crustal exhumation in Jersey is unknown, the weathering processes that have degraded the rock mass in parts of northern France and southern England would also have affected the exposed geology in Jersey. This includes prolonged chemical weathering under temperate Cenozoic climates prior to the Late Miocene and mechanical forms of weathering under cold-stage Plio-Pleistocene climates. The depth of this weathering profile in Jersey is not known with any certainty, but in comparable rocks in mainland UK, it is around 80 m.

Throughout the Cenozoic, the interplay between compressive Alpine crustal stresses and the ongoing opening of the North Atlantic has controlled the evolution and geography of the English Channel and Jersey. This interplay has been responsible for modifying the base level and associated local sea levels in complex ways, creating planation surfaces in the landscape. Marginal areas of the Massif were periodically flooded during the Cenozoic, resulting in the accumulation of sediments of that age. One of these events, which occurred during the Eocene, encroached into the shallow embayment of the Normanno-Breton Gulf, depositing bioclastic limestones. These deposits provide the first evidence of the islands as separate areas of land distinct from the mainland (information from J Renouf).

2.5 QUATERNARY GEOLOGY

Introduction

Throughout the Quaternary (the past 2,600,000 years), the predominant influence on the environment of much of North-west Europe has been glaciations, and its landscape is largely the product of erosion and deposition by ice sheets and glaciers. Jersey and the other Channel Islands all lay beyond the margins of the ice sheets, in a periglacial zone, throughout the Quaternary, so there are no glacial sediments or landforms present on the Islands (Keen, 1978b). Instead, Jersey's landscape and environment was dominated by the interplay between periods of erosion and deposition in response to global and regional changes in the climate and sea level, which were due to global ice sheet growth and decay, as well as local active neotectonics. The resulting changes in the base level led to cyclical periods of erosion and deposition that occurred around coastal areas and in valleys. Neotectonic processes are important, as they are responsible for the regional uplift that has ensured the preservation of the various wave-cut notches seen around Jersey, beyond the reach of later marine erosion (information from J Renouf).

Variations in the sea level would have resulted in changes to the shape of Jersey's coastline, and at times base levels would have been low enough to make the present-day island part of a larger plain connected to the continent, facilitating the migration of Neanderthals across the region. Consequently, the Quaternary in Jersey includes both marine deposits and landforms, including raised beaches and erosional wave-cut notches, as well as sequences of terrestrial deposits, such as periglacial head and loess that have not been removed by erosion, and later windblown sand and peat.

During the Quaternary cold stages, periglacial conditions dominated North-west Europe beyond the ice-sheet margins, and like the wider region, Jersey endured a cold and arid climate with little vegetation to stabilise the unconsolidated surface sediments (Keen, 1978). As a result, the mobilisation of silt and fine sand by aeolian (wind) mechanisms was the major geomorphological process that caused windblown deposits to dominate the Quaternary sequence in the central, flatter part of the island (Keen, 1978, 1993). Furthermore, the combined products of freeze-thaw and mass movement processes have locally resulted in the formation of significant deposits containing a high proportion of clasts of frost-shattered bedrock; these deposits mantle inland slopes and accumulate below the coastal sea cliffs.

During the Quaternary warm stages (interglacials), the climate of the Normanno-Breton Gulf was similar to its climate today. Jersey's bays contain recent accumulations of peat and silt deposits, and similar deposits had also formed on parts of the surrounding plains before they were submerged by the rising post-last-cold-stage sea level. There are many preserved examples that occur at middle to low tide levels around the island and at different levels within the sediments that occupy the main bays of the island. The peats and the associated generally fine-grained sediments contain material and artefacts that relate to the human occupation of Jersey (information from J Renouf).

The more recent deposits, in the form of peat and alluvium in coastal areas, date from the Holocene. These Holocene sediments are locally interbedded with marine deposits along the coast, which record a history of marine transgressions into freshwater bodies that coincided with the deposition of windblown sands nearby (Figure 9).

Quaternary climatostratigraphy

In order to distinguish between warmer and colder phases during the Quaternary Period, the variation in oxygen isotopic ratios measured from long sediment and ice core records is used. These ratios provide a proxy measurement for the extended periods when relative volumes of water trapped in global ice masses have varied over time, with larger ice volumes resulting in lower sea levels and vice versa. These extended periods are referred to as Marine or Oxygen Isotope Stages (MISs or OISs). It is generally accepted that there are three categories:

- Glacial or cold stages (even-numbered stages) correspond to freezing cold conditions and the global existence of large ice sheets, with resulting low sea levels.

- Interstadial events correspond to minor climatic ameliorations superimposed upon cold stages. These events do not have widespread glacial conditions. For example, most of Europe would have been dominated by tundra-like conditions during these events.
- Interglacial or warm stages (odd-numbered stages) typically correspond to stages in which climates were similar to or warmer than the present day. For example, hippo and lion remains have been found in English interglacial sediments. These periods are associated with relatively higher sea levels.

Warm stages (interstadials and interglacials) in North-west Europe are denoted by odd MIS/OIS stage numbers, for example, OIS 1 (the Holocene) and OIS 3 (the Middle Devensian). Cold stages (glacials) have even numbers, for example, OIS 2 (the Late Weichselian / Late Devensian).

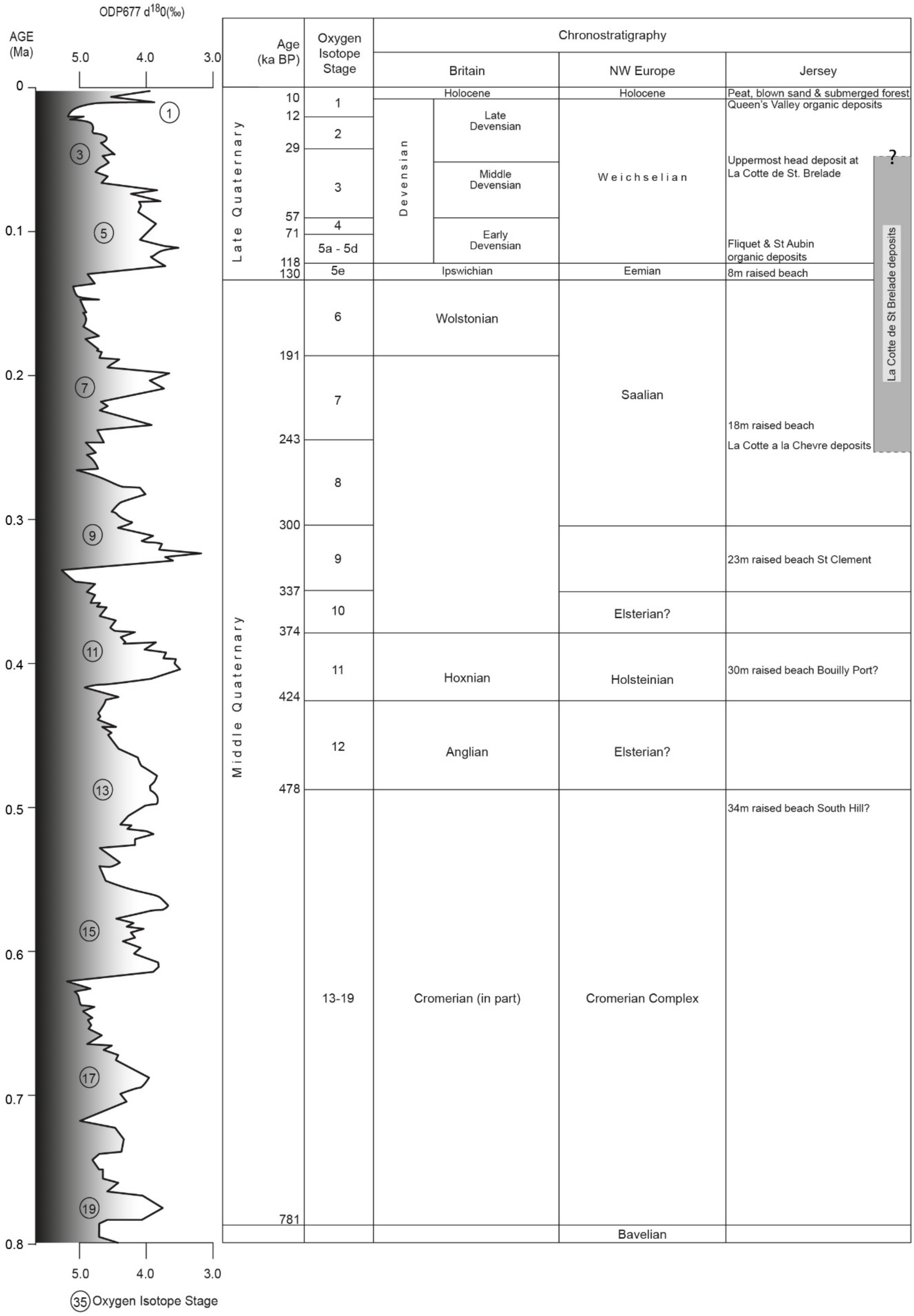


Figure 8 **Chronostratigraphy of the Middle and Late Quaternary Period, 0.8 Ma to present, showing major stages in the British Isles and Europe; Oxygen Isotope Stages (OISs) and graph indicating relatively warmer or cooler periods; and significant events in Jersey's Quaternary history (after Merritt *et al.*, 2003; Lee *et al.*, 2015).**

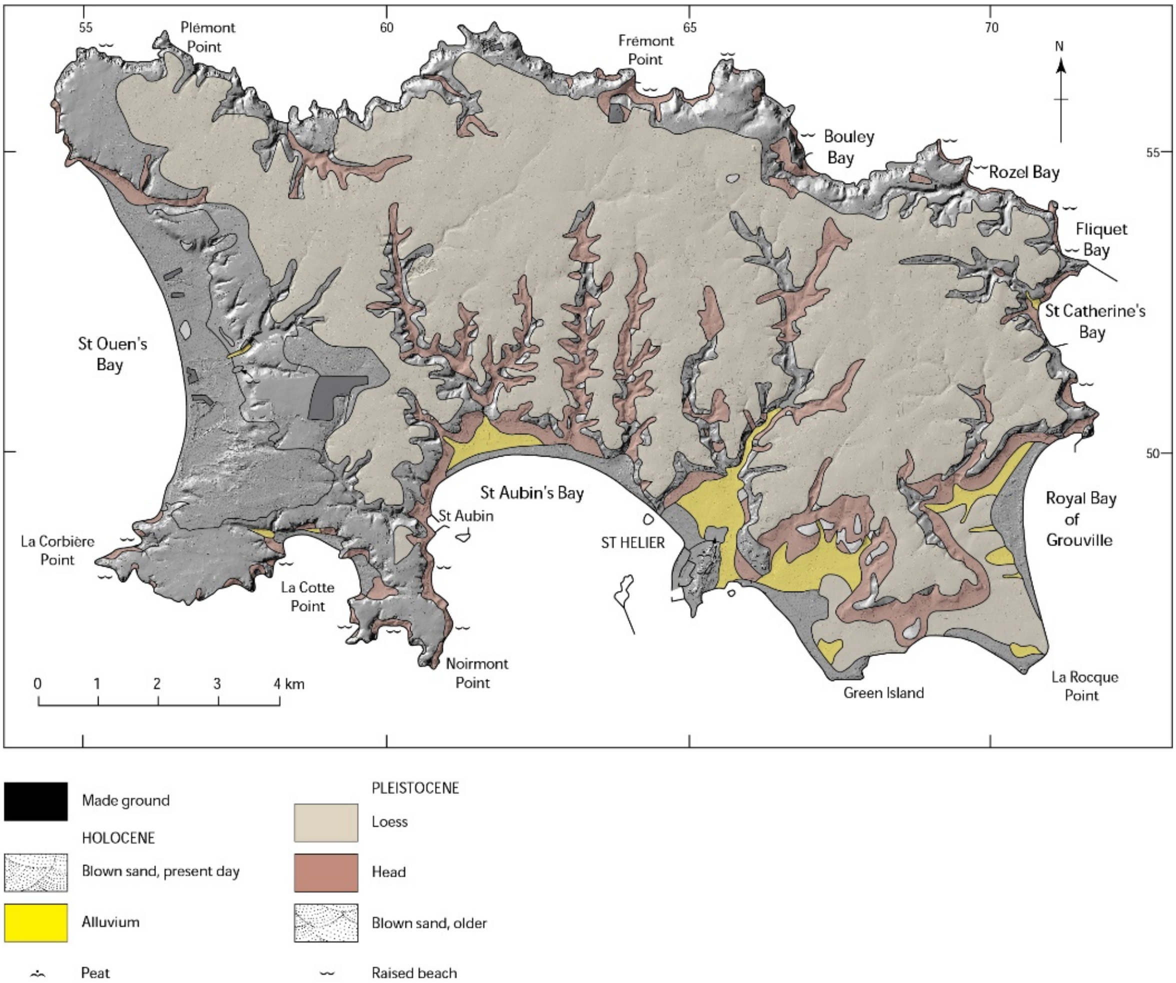


Figure 9 **Sketch map of superficial (Quaternary and recent) deposits (after Bishop and Bisson, 1989).**

Chronology

Quaternary deposits cover much of Jersey but have yet to be systematically dated and characterised in terms of their palaeoenvironmental and archaeological potential, except in a few key localities. However, through recent studies, significant progress has been made in dating and correlating deposits from many locations on the Island and in placing them in at least a local stratigraphy. Furthermore, some sites in Jersey have also been successfully correlated more widely, allowing a comparison with the climatic and environmental conditions established in studies of sites in the wider Channel region and northern France. A list of the sites and sampled materials from the Jersey pre-Holocene Quaternary succession, for which absolute dates have been published, is shown in Table 2. Dated sites extend back almost 250,000 years, but parts of the sequence, notably the highest raised shoreline features, are thought to be much older, possibly reaching back to Oxygen Isotope Stages (OISs) 11–13 (*c.* 390–490 ka BP; Renouf and James, 2011; Figure 10).

The chronostratigraphical framework for many of the Holocene sequences is better constrained, principally because these sequences often include peats, organic muds and plant remains that are suitable for ^{14}C dating. It is clear from the published ages that the maximum (high stand) of the Holocene sea-level transgression in Jersey was reached around 4,000 yr BP (Stéphan and Goslin, 2014). Holocene peat and alluvium began to be deposited *c.* 8 yr BP and most of the blown sand of the southern and western coasts is younger than 4,000 yr BP (Jones *et al.*, 1990). In contrast to Pleistocene sequences, which are rather fragmentary, the Holocene sediments often bury extensive pre-existing landscapes. For example, in St Ouen's Bay the blown sand buries a mid-Holocene landscape associated with evidence of human activity, including stone monuments and dwellings dating to the Neolithic Period.

RADIOMETRIC DATES FROM THE PRE-HOLOCENE SEQUENCES						
LOCALITY	MATERIAL	DATE (ka)	ERROR (ka)	Calibration (14C)	METHOD	SOURCE
Queen's Valley Reservoir	Organic silt (top)	10,490 14 C years	± 0.70	12,880–11,960	14 C	Jones *et al.* (2004)
Queen's Valley Reservoir	Organic silt (base)	10,720 14 C years	± 0.130	13,120–12,190	14 C	Jones *et al.* (2004)
Fliquet	Twigs from peat	>25.5 14 C years			14 C	Coope *et al.* (1980)
La Cotte de St Brelade	Final head deposit	25.7	± 3		OSL	Bates *et al.* (2013)
Portelet	Dune sand (overlying 8 m raised beach)	96*	± 12		TL on K feldspar	Vliet-Lanoë *et al.* (2000)
La Cotte de St Brelade	Sediment 3–4 m beneath deposits containing hominid remains, artefacts and animal bones, above raised beach	102 ± 15.8 – 47.9 ± 2.16			OSL	Bates *et al.* (2013)
Belcroute	Beach sand	109**	± 20		TL on K feldspar	Vliet-Lanoë *et al.* (2000)
Belle Hougue	Travertine cement (8 m raised beach)	121	+14/-12		U-Th	Keen (1981)
Belle Hougue	Marine mollusca (8 m raised beach)	*c.* 120			AAR	Keen (1981)
La Cotte de St Brelade	Burnt flints (layers C, D and E)	238	± 35		TL	Callow and Cornford (1986)

** This material gave a range of ages from 64 ± 7 to 96 ± 12 ka BP in a review of Tl dates by Balescu and Lamothe (1992).*
*** This material gave a range of ages from 60 ± 9 to 109 ± 20 ka BP in a review of Tl dates by Balescu and Lamothe (1992).*

Table 2 **Absolute age dates from the pre-Holocene sequences**

2.5.1 Raised beaches

The evidence for past high relative sea levels is widespread along the coastlines of the Normanno-Breton Gulf, including the coasts of Jersey and the other Channel Islands as well as those of the Cotentin Peninsula and Brittany. This evidence includes wave-cut notches and platforms cut into the bedrock, as well as raised beach remnants that occur at a wide range of elevations above the present mean sea level. However, Keen (1995) highlighted the fact that the regional correlation of these raised marine features based simply on their position/altitude relative to the present day mean sea level (m.s.l) remains problematic for the following reasons:

1. The tectonic setting and degree of neotectonic uplift and depression may have varied greatly between these sites throughout the Cenozoic (Vliet-Lanoë *et al.*, 2000).
2. The pattern (and number) of global eustatic sea-level changes (caused by global climate change and the consequent growth and recession of ice sheets and glaciers) throughout the Quaternary is highly complex.

3. The present-day tidal ranges in the wider Channel Islands region, notably between Guernsey and Brittany, are some of the largest in the world (Renouf and James, 2010). Consequently, if the extrapolation of similar tidal ranges back to the Quaternary Period is performed, contemporaneous beaches and marine planation surfaces recognised at the different sites in Jersey will have formed at different elevations relative to the local m.s.l. compared to similar sites in the Channel Islands and adjacent French coasts.

Vliet-Lanoe *et al.* (2000) further highlighted the difficulties in correlating between sites by comparing the published radiometric (U-Th), optically stimulated luminescence (OSL), thermoluminescence (TL) and electron spin resonance (ESR) ages of different deposits. The ages obtained for beaches at elevations of 6–10 m above NGF (Nivellement general de la France) at Pen Hat (West Brittany), Menez Dregan (West Brittany), Pénestin (South Brittany) and Trez Rouz (West Brittany) range between *c.* 377 ka BP and *c.* 470 ka BP (Vliet-Lanoe *et al.*, 2000). These ages fall close to the ages (*c.* 395 ka BP or *c.* 490 ka BP) proposed for the '30 m' beaches at **South Hill** in Jersey and at Les Vardes on Guernsey (Renouf and James, 2010). However, the elevations of the dated sites in Brittany are similar to those of the 8 m raised beaches in Jersey, which typically have been assigned ages of between *c.* 96 ka PB and *c.* 230 ka BP; however, sea levels recorded in southern Brittany are thought to have distinct ages from those of the Normanno-Breton Gulf, being subject to a different tectonic regime (information from J Renouf).

Despite these difficulties, recent advances have been made in placing the raised shoreline history of Jersey into a more robust regional chronological framework (Renouf and James, 2011; Table 2). Currently, six separate Quaternary high sea-level stands have been identified in Jersey, but only four have beach deposits associated with them. The others are represented by palaeo-cliff lines and marine notches cut into bedrock. The first and highest, referred to as the '30 m' shoreline, occurs at **South Hill, St Helier**; its only known possible correlative at present is that of Maupertus-le-Grand-Castel in the Val de Saire east of Cherbourg in Normandy (Coutard, 2003). Mourant (1933) and Coutard suggested that both of these ± 40 m beaches extend over a range of heights down to *c.* 30/31 m. Unlike the South Hill and Val de Saire 40 m beaches, which could be assigned to a single, if composite, event, there are several known, apparently standalone 30 m beaches and notching in the Val de Saire (Platform IV, Coutard, 2003), Guernsey (Keen, 1978; Renouf and James, 2010) and Jersey (Bouilly Port, St Brelade; Nichols and Renouf: Jerseygeologytrail.net/superficial deposits). Renouf and James (2010) suggest that these 30 m raised beaches date to *c.* 400 ka (OIS 11) depending on what rate(s) of tectonic uplift is applied to the land surface over the last 500 ka. The next-lowest raised beach occurs at an elevation of 23 to 24 m at St Clement and most likely dates from between 303 to 339 ka (OIS 9; Renouf and James, 2010). This beach is probably present at the archaeological site of Les Varines, where marine sands at the foot of the old cliff have been proven through drilling to be present between 23 and 27 m. Here, they rest on granitic sand rather than directly on the wave-cut platform, suggesting that this feature may in fact represent two or more high sea-level events rather than the one event argued for by Renouf and James (2010) (information from J Renouf).

Remnants of a third shoreline at an elevation of 18 m a.m.s.l. are common, particularly along the northern coast of Jersey, with the key sites being identified at Le Pinacle,**Ile Agois**, **La Cotte à la Chvre**, Belle Hougue Cave I and II and elsewhere. Elements of the 18 m raised beach almost certainly exist on the southern side of the Island but are typically buried beneath head in the embayments east of St Helier. For example, an extensive sequence of 8 m or more of marine sands has been mapped at the base of the cliff at Les Varines, where marine sediments rest on a platform covered with granitic sand; this suggests that at least two high sea-level events occupied this shore platform. This shoreline level has been correlated with Platform II in the Val de Saire (Coutard, 2003) and at La Roche Geletan (Cliquet *et al.*, 2009) and dates from around 240 ka BP. A resurvey of La Cotte à la Chèvre (Renouf and James, 2010) found that the cave floor was lower than previously thought at 14 m a.m.s.l. and also placed this feature in the 18 m group of beaches and notches. Callow (1993), and subsequently Renouf and James (2011), attribute **La Cotte à la Chvre** cave deposits to this period of shoreline formation. Bishop *et al.* (2003) reported the presence of a small remnant of travertine-cemented gravel, which they assigned to the '18 m' raised beach, in the higher of the two caves at **Belle Hougue Cave I and II.** This deposit of travertine with stalagmites occurs on the surface of a fault sloping down from the 18 m notch to the 8 m notch and cannot be reliably linked to formation at the time of the 18 m notch (information from J Renouf).

The ‘8 m’ raised beach is the most common raised shoreline identified around the coast of Jersey and is particularly well developed at **Le Pulec**; it extends around the present low water mark as dissected remnants (Renouf and James, 2011), around the **Giffard Bay**, **Bonne Nuit** and Rozel in the north and around the **Bouley Bay, Portelet** and **Belcroute** in the south of the Island (Keen, 1993, 1995). The Holocene beach deposits are composed of a wide range of clast sizes, from 40 cm cobbles at **Portelet Bay** to fine gravel and sand at **Belcroute**. Although they are typically dominated by locally derived bedrock, locally these beach gravels contain distinctive clasts, such as jasper pebbles at **Giffard Bay** and significant amounts of flint at **Bonne Nuit**. Iron-cemented gravels at mid-intertidal to mid-upper tidal levels are found widely around Jersey’s coast, suggesting that they have a common origin. A possible source of iron could have been groundwater carrying iron to emergence down the tidal beach (information from J Renouf). A good example is the iron-cemented gravels recorded by Bishop *et al*. (2003) ‘forming an upstanding mass in the modern beach’ east of Noirmont Point, near Portelet.

Keen (1993) provides a good account of the marine sediments in Jersey along with their possible ages. Subsequent research has identified pockets of sediment on the present intertidal reefs of Jersey that do not readily fit the present accepted consensus of a single 8 m sea level followed by one set of cold stage deposits and then the deposits of the Holocene. For example, flint artefacts at upper mid-tide levels at Petit Portelet suggest a pre-OIS 5e date, and Cold Stage loesses and/or head below 8 m cobble beaches at both Portelet and Belcroute indicate that they are related to composite OIS 5e succession, allowing for a cold phase within that stage or a wholly pre-OIS 5e (likely OIS 6) age for the latter. If correct, this would demonstrate that the rock platform on which the lowermost cold stage deposits rest must have an origin at least as old as OIS 7 or that there are additional unknown sea-level stands (information from J Renouf). In the absence of an extensive dating programme for the raised shorelines, possibly using more modern techniques (e.g., revised ^{14}C [AMS ^{14}C], thermoluminescence [TL], optically stimulated luminescence [OSL] dating, terrestrial cosmogenic nuclides [TCN]), this chronology will remain poorly constrained, perpetuating the differences in the interpretation of these features.

2.5.2 Quaternary terrestrial deposits

2.5.2.1 LOESS

Loess, in the form of an apparently structureless orange-brown silt, is widespread across Jersey and mantles *c.* 75% of the plateau surface of the Island. It is thickest around St Clement and on the plateau around **La Hougue Bie**, where it is reported to be up to *c.* 5 m thick, but elsewhere it is commonly less than 3 m thick, for example, at **La Motte (La Motte, Le Nez and Le Croc SSI),** St Peter and St Ouen. The thickest deposits are generally found in the east of Jersey, thinning westwards (Keen, 1993). There are also significant loess deposits with head deposits on the south, east and north coasts of the island. These fine-grained silty sediments are mainly composed of detrital quartz and feldspar grains, and they are predominantly transported by strong katabatic winds blowing from the north-west ice-covered regions towards Brittany and Normandy (Lefort *et al.,* 2019). Pleistocene loess with an easterly derivation is also recorded (information from J Renouf). Locally, however, calcareous loess deposits have been reported, most notably at La Motte and Belval Cove, with these aeolian deposits containing diagenetic calcareous concretions (Keen, 1993). Structures called ‘limon à doublets’, which are related to the relatively rare combination of decalcification and bioturbation processes, are also present at La Motte and in the upper part of the section at **Belcroute.**

The calcareous loess at **Portelet**, Belval and St Aubin’s Bay has yielded sparse fossil assemblages, including land snails of Arctic affinity (Keen, 1993; Rousseau and Keen, 1989). Fossil snails have also been recovered from calcareous patches within the uppermost loess unit at Belcroute Bay. Cold climate molluscan faunas in loessic sediments are also known from sites on Guernsey, as well as in Normandy, Brittany and Sangatte near Calais. The fauna from the loess at the Portelet site in Jersey, coupled with its stratigraphical setting (Lautridou *et al*., 1986), enabled Rousseau and Keen (1989) to produce a tentative comparison with the tundra

(*Columella*) faunal assemblages from loessic sequences at Bréhat in Brittany and Le Havre in Normandy. The Portelet assemblage was from loess located within a channel cut into pre-existing head deposits. These rest upon pedogenically modified windblown sand, which overlies the ‘8 m’ raised beach deposits. This entire sequence occurs beneath a geliflucted layer within the loess that has been correlated with the ‘Kesselt level’ of Normandy; the latter is considered to mark the Upper Weichselian–Middle Weichselian (Devensian) boundary (*c.* 25–30 ka BP) in North-west Europe. This means that the fauna at Portelet is probably only a little older than 30 ka BP, i.e., potentially within the limits of modern AMS ^{14}C dating. This would enable an absolute age to be established for this part of the loess sequence in Jersey.

Although they most certainly pre-date the Holocene, the age of the loessic deposits in Jersey does vary, as in some areas they are observed underlying Middle Pleistocene deposits, whereas elsewhere they rest directly on head of Late Pleistocene age. The presence of loessic material incorporated within the lowermost part of the sequence from the **La Cotte de St Brelade** ravine complex (Callow and Cornford, 1986) led Keen (1993) to suggest that loess deposition in Jersey may have begun as early as OIS 8 (>245 ka BP). Furthermore, recent work at Les Varines indicates that the localised reworking of loess during the Late Pleistocene and even into the early Holocene has produced sediment sequences very similar to *in situ* loess, and consequently the most recent loess-like deposits may contain a variety of ages of material.

2.5.2.2 HEAD

During cold climate conditions, repeated freezing and thawing causes the frost shattering, disaggregation and erosion of exposed bedrock surfaces. The gravitationally driven downslope movement of this broken material due to a combination of solifluction, gelifluction, debris flow and soil creep can lead to the accumulation of a significant thickness of material at the bases of slopes. These typically poorly sorted (boulder to silt), massive to weakly stratified deposits, called ‘head’ deposits, occur in many coastal locations across Jersey. Head thicknesses can reach up to 20 m along the base of ancient, abandoned palaeo-sea-cliffs, and the thickness of the coastal head deposits is directly related to the height of the palaeo-cliffs, with a ratio of cliff height to head thickness of *c.* 4 or 5:1 (Keen, 1978). Similar ratios have been reported from head-blanketed cliff sections on the Cotentin Peninsula in Normandy by Watson and Watson (1970) and in south Devon by Mottershead (1971).

Along the inland fossil cliffs backing the main bays of **St Ouen’s** and St Aubin’s, head deposits are observed forming fans and cones, which are partially buried beneath later windblown sand. Head also occurs inland in Jersey; however, these deposits tend to be much thinner, mantling the lower valley side slopes to a maximum depth of 2–3 m. The inland head deposits tend to be finer grained than those exposed at the coast, as they are mainly derived from the loess with mantles from the plateau above. For example, at Les Varines, it is difficult to distinguish *in situ* loess from reworked loess deposited in the early Holocene.

Almost all of the island’s head deposits contain a proportion of loess. The loess is either distributed relatively ubiquitously throughout the head as a matrix, as lenses of up to 2–3 m thick and tens of metres long (particularly characteristic of north and south-west coastal heads, e.g., Bonne Nuit/Giffard, Beauport), or as sheets (as observed at Belcroute and Portelet). Slope processes are responsible for redistributing loess from the plateau and adding it into the coarser head accumulations lower down, as at Les Varines. Redistributed loess and other finer-grained deposits accumulated during overall head formation, as seen very clearly towards the eastern end of Bonne Nuit, where finer-grained material is derived from upslope by rivulets locally causing shallow ponding (Bishop and Bisson, 1989). At some localities, e.g., Petit Portelet below Mont Orgueil Castle, Belcroute and Portelet, head with thicknesses of between 1 and 2 m underlies cobble gravels of the 8 m beach and rests on bedrock, leading to the assumption that these periglacial slope deposits are pre-Ipswichian in age (information from J Renouf).

At **La Cotte de St Brelade**, the head deposits contain faunal remains and anthropogenic artefacts, including the bones of mammoths, rhinoceros, rodents and birds, along with the tools and bones of Neanderthals; as a result, the site is of international archaeological significance, with head deposits dating back to >240 ka BP (Huxtable, 1986). At **Fliquet,** peat containing beetle and pollen taxa, indicative of formation in a sub-Arctic environment, has been incorporated into the base of the head deposits.

Almost all the known head deposits occurring in Jersey are considered to have last cold stage (Devensian) ages, and known older head deposits are confined to a few specific sections, such as at Portelet, Belcroute and Petit Portelet and the complicated, even older successions within La Cotte de St Brelade (information from J Renouf).

2.5.3 Devensian and pre-Holocene organic deposits

The **Fliquet** site is one of only three sites in Jersey where pre-Holocene organic sediments (muds and peats) have been recorded. Peat overlying organic-rich mud, resting on a wave-worn surface cut in rocks belonging to the *Jersey Shale Formation*, was exposed from beneath the modern storm beach at St Aubin's Bay (**Belcroute**) during the storms of 1981 (Coope *et al*., 1985, 1986a, b, 1993). The deposits at St Aubin's have several similarities to the Fliquet sediments, with both sequences containing angular and rounded clasts of shale, suggesting that these organic sediments have been reworked, i.e., they are head with a matrix of organic-rich sediment. Both the St Aubin's Bay and Fliquet sediments are described as 'compacted' and have yielded pollen spectra and fossil coleopteran (beetle) assemblages that indicate deposition under tundra (Arctic) conditions. The St Aubin's Bay deposits are undated, but the flora and faunal assemblages they contain can be used to suggest that they were formed during a cold stage in the Early Weichselian (OIS stages 5a–d) or earlier.

The organic sediments at Fliquet and St Aubin's Bay have been compared with similar sequences from Omonville-la-Rogue, Baie de Ecalgrain, Herquemoulin, Petit-Beaumont and Vauville on the Cherbourg (Cotentin) Peninsula in Normandy (Coope *et al*., 1986a, b). Coope *et al*. (1985) noted that, at the time, no analogous pre-Holocene organic deposits were known from the British coast. Although Coope *et al*. (1980) compared Fliquet to the dated sequences at Kerguillé, Finisterre, Port-Lazo and Côtes du Nord in Brittany, as well as those at St Côme de Fresné (Calvados), Baie de Ecalgrain and Vauville in Normandy, the dating of all of these French sites has subsequently proven to be problematic. For example, the organic sediment at St Côme de Fresné overlies estuarine deposits and was originally assigned to the Ipswichian (Eemian) warm stage. However, palynological analyses indicated that these sediments contain a high percentage of tree pollen (including pine) in the profile, which is incompatible with the cold 'Arctic' environment suggested by the floral and faunal assemblages acquired from the Fliquet sediments.

In their initial study, Coope *et al*. (1980) suggested that the most comparable sites to Fliquet were at Port-Lazo (Brittany) and Vauville (Normandy), which have been assigned late Brørup (OIS 5c; *c.* 92–105 ka BP) and Late Weichselian (*c.* 24 ka BP) ages, respectively. In their study of the 'detrital peat' at St Aubin's Bay, Coope *et al*. (1985) suggested that the flora and fauna in the sediments from Jersey most closely resembled those reported from organic sediments at Petit-Beaumont and Herquemoulin on the Normandy coast and that they all probably formed during an Early Weichselian (Early Devensian) interstadial episode. This would have occurred prior to the onset of the main Late Weichselian (Late Devensian) cold stage (*c.* 30 ka BP), which is thought to have been responsible for the most recently preserved major phase of periglacial activity in Jersey. In summary, it appears that the organic sediments at Fliquet and St Aubin's Bay in Jersey and comparable sequences on the Normandy coast provide evidence of a similar pattern of the climate, vegetational and relative sea-level change and that these changes occurred during the late Eemian to Early Weichselian (late Ipswichian to Early Devensian; OIS stages 6–5a).

Pre-Holocene deposits of organic silt and sand, intercalated with head containing clasts of granitic and volcanic rocks, were exposed in an excavation for the construction of the Queen's Valley Reservoir in eastern Jersey (Jones *et al*., 2004). The organic sediments at this third site yielded pollen, plant macrofossils and coleopteran remains that indicated that they were deposited under periglacial conditions. The included plant remains yielded a ^{14}C date of 10,490–10,720 ^{14}C yr BP (*c.* 12,020–12,520 cal ^{14}C years ago), which is consistent with these sediments having been laid down during the early part of the Loch Lomond (Younger Dryas) Stadial, i.e., they are much younger than those from Fliquet and St Aubin's Bay. Jones *et al*. (2004) noted that similar Younger Dryas vegetational sequences have been found at Bellengreville (Calvados), Saint Ursin, La Vie and Le Fourneau (Mayenne) in Normandy within the Massif Americian. These authors also discuss the context of the Queen's Valley site in Jersey in relation to sites of a similar age in the Somme Basin in northern Belgium, the Gatcombe Withy Bed and Munsley Peat Bed on the Isle of Wight, the Church Moor site in the New Forest, Holywell Coombe near Folkestone and the Hawkes Tor site on Bodmin Moor. The Queen's Valley Reservoir organic sediments are important not only in a regional context, but also because they are the only robustly dated sequence of pre-Holocene humic organic sediments in Jersey. As a consequence, they provide unique evidence of the environment, vegetation and climate on the Island during the Weichselian cold stage, immediately prior to the Holocene.

2.5.4 Pre-Holocene blown sand

Windblown sand up to 5 m thick, known as the St Peter's Sand, underlies the area beneath the eastern part of Jersey Airport. The sand is not currently exposed; however, it has been recorded in a road cutting by Keen (1975), where it was overlain by loess. Similar pre-Holocene blown sand deposits have been identified within the head- and loess-dominated sequence at Portelet Bay, where they are partially cut out by a channel of probable Weichselian (Devensian) age that is infilled by loess containing Arctic snail fauna. Although precise dates on the loess deposits of Jersey have not yet been obtained, this indicates that the most recent period of formation for this blown sand deposit is pre-Holocene, possibly during the Younger Dryas or even earlier.

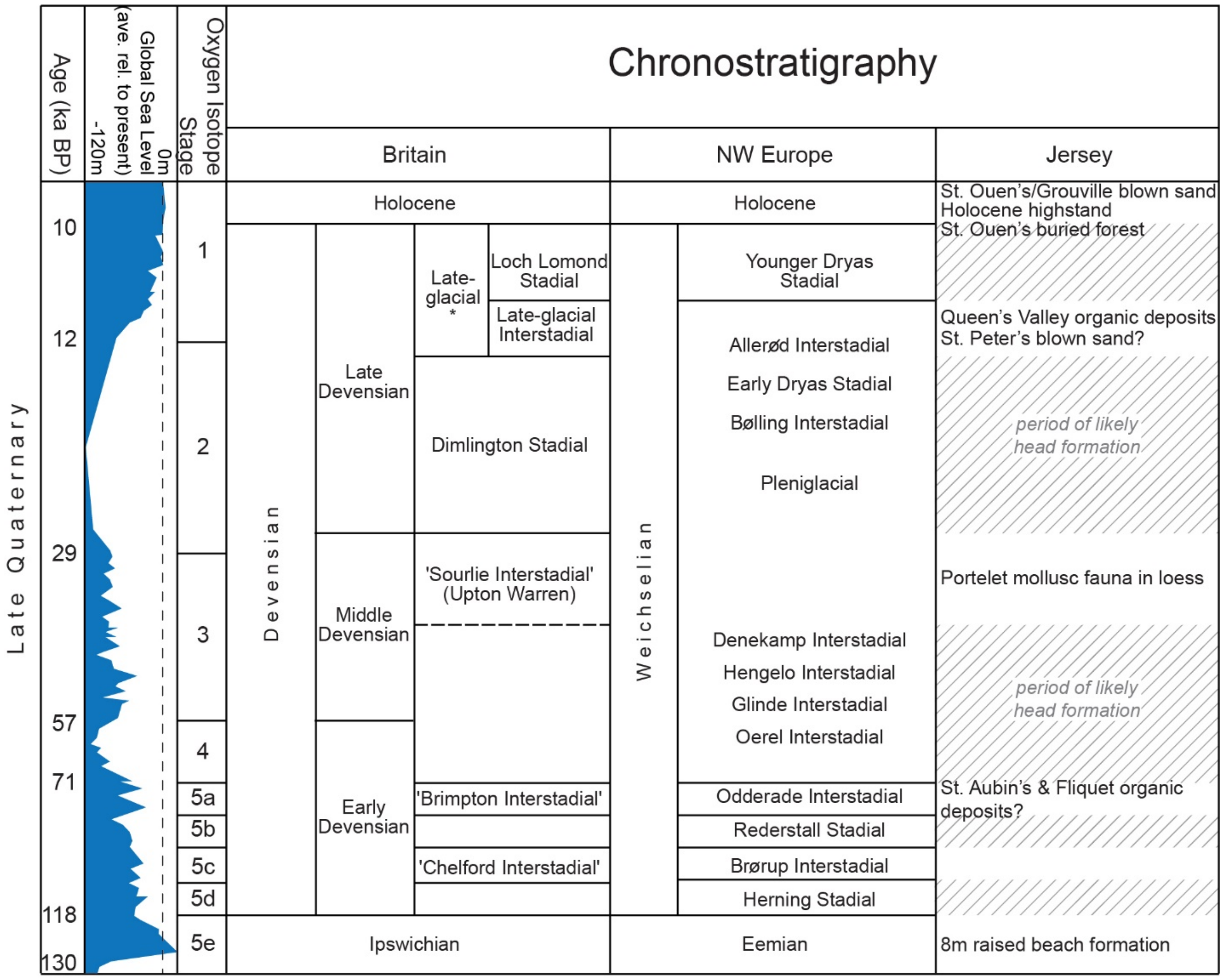


Figure 10 **Detailed chronostratigraphy of the Late Quaternary, showing global relative average sea level; Oxygen Isotope Stages (OISs); key divisions of the period in both Britain and North-west Europe; and significant events in Jersey's Quaternary history (after Merritt *et al.*, 2003; Lee *et al.*, 2015).**

2.5.5 Holocene deposits

2.5.5.1 BEACH DEPOSITS

There are many small beaches on the Island comprised of a mix of cobbles and coarse sand. The greatest expanse of modern beach deposits, however, can be found in St Ouen's Bay on the west side of the Island, St Aubin's Bay in the south and Grouville Bay in the south-east. Behind several of the larger beaches are contemporary wind-blown sands that form mature dune systems, especially around St Ouen's Bay.

2.5.5.2 ORGANIC DEPOSITS

Peat and alluvium and alluvium that also contains peat can be found in the mouths of the major river valleys along the south coast of Jersey at St Aubin, St Helier and Georgetown. Furthermore, peat has also been recorded underlying the blown sand at **St Ouen's**, **St Brelade's** and Grouville bays. Thick organic deposits comprising up to 8.5 m of organic silts and muds, in association with up to 2 m of peat, have been recorded at Grouville Marsh (Jones *et al*., 1990; Keen, 1993). Coastal organic sediments, although they contain an assemblage dominated by freshwater pollen taxa, reveal a history of marine transgression throughout the Holocene; at least two such events are recorded in the sedimentary sequence exposed at **St Ouen's Bay**. Inland, the basal peats analysed from the St Peter site have early Holocene ages of 10,830 ± 70 yr BP (9,670 ± 70 ^{14}C yr BP), with the pollen sequence recording changing environmental conditions through the Holocene, including the impact of increasing human activity.

Although they are not widespread, there are alluvial deposits in the north-south-oriented river valleys draining to the south of the Island. These deposits comprise a rich, dark orange-brown organic sandy silt with occasional gravels.

2.5.5.3 BLOWN SAND

Blown sand deposits are extensive in the west of Jersey at **St Ouen's Bay**, at Grouville in the east and at **St Brelade**, St Aubin and St Clement in the south, with a small area of these deposits also occurring at Grève du Lecq in the north. The windblown sands directly overlie peat, with the ^{14}C ages acquired from the top surface of these organic deposits indicating that sand deposition started after *c.* 4,310 yr BP (3,980 ^{14}C yr BP) in St Ouen's Bay and slightly later, after *c.* 3,275 yr BP (3,150 ^{14}C yr BP), at Ouaisné. The deposition of windblown sands on the Island has continued intermittently to the present day (Keen, 1993), with a major occurrence dated to the early 13th century (Le Cornu, 1883). The superposition of the blown sand over organic deposits such as peat from multiple coastal localities reveals a story of rising Holocene sea levels, where peat and alluvium deposition occurred in ponds protected by beach bars until they were breached by the rising sea level. As the sea level rose, blown sand progressively encroached into these freshwater environments as the beaches became established (Keen, 1993).

2.5.5.4 OTHER DEPOSITS

There are also other, less well-known sediment types present in Jersey. For example, at St Clement's Parish Hall car park and on the foreshore to the west of the Le Hocq Tower, there are peats containing tufa of possible Holocene age. The peats in Jersey are rich in molluscs, which is regionally uncommon; molluscs can be used for high-resolution dating and so further research into these molluscs could provide important insight into the timing of climate change. Also important for dating are the flowstone deposits from the cave Belle Hougue I. It is not known if there are any left *in situ*, but any material retained in museums could potentially be the best chance of discovering long climate records in this part of the region. Similar deposits from Northern France are not known.

2.6 THE PREHISTORIC RECORD

The prehistoric archaeological narrative of Jersey, covering a span of time in excess of 250,000 years, up to and including the Iron Age, has been shaped by factors that include both the archaeology itself and the history/context of excavation on the island. Consequently, we can identify the following factors as important:

- 'Big sites' such as La Cotte de Saint Brelade (Callow and Cornford, 1986) and La Hougue Bie (Patton *et al.*, 1999) dominate the narrative of the Island.
- Prior to the post-war era, most visible and prominent sites were excavated by members of the Société Jersiaise, the Island's learned society. Very few key sites have been subject to modern scientific investigation.
- Only recently has an Historic Environment Record been established for the Island. This is an ARCHES database that is maintained by Jersey Heritage.
- Planning regulations have not always considered geoarchaeological potential or landscape-scale preservation.
- Very little purposive prospecting for buried prehistoric archaeology has been undertaken on the Island.

Additionally, we need to consider the differences in the nature of the archaeological signatures associated with the prehistoric record. Thus, for the Palaeolithic and Mesolithic periods (up to *c.* 6,000 years ago), it is perhaps best to consider the archaeology of the period as a resource distributed across the landscape in differing densities according to both the use of that landscape by past human populations as well as the varying nature of the Quaternary geology. This eschews the use of the term site (appropriate for the Neolithic, where substantial structures are present) for this early archaeology and replaces it with the concept of the spatial use of the landscape, which results in different archaeological signatures across that landscape. Such an approach moves away from the concept of large accumulations of artefacts being significantly more important than perhaps small assemblages at key locations in a landscape. Consequently, for the Palaeolithic we can identify the following:

1. Sites with large quantities of artefacts, for example, La Cotte de Saint Brelade (Callow and Cornford, 1986; Shaw *et al.*, 2016), Les Varines (Conneller *et al.*, 2016) and Canal du Squez (Conneller *et al.*, 2016)
2. Sites with moderate numbers of artefacts (10–150), for example, Petit Portelet
3. Sites with low numbers of artefacts (1–10), for example, Le Pulec.

2.6.1 High-density Palaeolithic/Mesolithic archaeological sites

Later prehistoric sites of Neolithic age are simpler to classify and can be more easily accommodated into existing frameworks of understanding; in the context of Jersey, they fall into two groups. First and most characteristic of Jersey are the upstanding megalithic sites of Jersey, including the major site at La Hougue Bie (Patton *et al.*, 1999) and other smaller sites, such as the standing stones in Les Blanches Banques. Some of these sites were discovered buried beneath superficial sediments, such as that of the Gasworks Dolmen, which lay at a depth of 4.5 m in deposits mapped as alluvium (Kinnes, 1988), and the two structures of the Ville-és-Nouaux Dolmens buried in sand at St Aubin's Bay. Second, there are the more ephemeral but nevertheless very significant sites documenting German occupation, such as those at the Simon Sand quarry in St Ouen's Bay.

Key Palaeolithic sites include the iconic site of La Cotte de St Brelade (Shaw *et al.*, 2016). This site is preserved in a sea cave in the granite cliffs of south-west Jersey and is currently unique in the context of the Island and North-west Europe as a whole. The sequences preserved within the ravines span some 250,000 years and document sporadic Neanderthal (and possibly modern human) occupation of this preferred location in the landscape. Fauna is preserved in some parts of the sequence due to the buffering effect of the calcareous loess protected under the overhanging granite roof from the decalcifying impact of rainwater. The archaeological signature through the sequence varies, and this variation has recently been linked to the changing nature of the broader landscape and raw material availability. The sequence also contains the remains of at least two Neanderthal individuals. Today, the site is under renewed management in the face of deterioration due to increased storminess and long-term degeneration.

Another internationally significant site in Jersey is that of Les Varines in the Parish of St Saviour (Conneller *et al.*, 2016). This site sits on the top of an abandoned sea cliff and is preserved within Late Pleistocene loess. First discovered by chance in a potato field, artefacts have moved downslope from the site's source in Late Pleistocene/early Holocene colluvium. The centre of the site remains undisturbed, and the spatial distribution of artefacts and granite blocks indicates the positions of a number of hearths and structured working areas. The site contains very badly preserved faunal remains as well as engraved plaquettes comparable to others in North-west Europe from the Magdalenian Period.

Sites from the Mesolithic are slightly more common and key sites are present on the northern part of the Island, where high cliff lines are penetrated by steeply dipping valleys leading from the Island's interior to the coast. Sites such as Canal du Squez, Col de la Rocque and Les Marrioneux all lie on topographic high spots adjacent to such features and presumably represent high vantage points at times of lower sea levels for access to the lowland river systems of the Normanno-Breton Gulf (Conneller *et al.,* 2016). In all cases, these sites are preserved in shallow sequences of sand-dominated sediments with little stratigraphic integrity.

2.6.2 Moderate-density Palaeolithic/Mesolithic sites

Recent work by the La Manche Prehistory Group has identified the site at Petit Portelet as a moderate-density site with Middle Palaeolithic artefacts in near mint condition. Attention was drawn to the site through the efforts of fieldwalking by members of the Société Jersiaise over many years. Intermittent exposures of fine-grained silt on the foreshore allowed the trial excavation of pits over three summers, and a range of artefacts, including flakes and cores, have been recovered from the sequences. They have yet to be dated, but on the basis of their stratigraphic position and likely relationship with sediments in the cliff face, these deposits may well date to early in MIS 6.

2.6.3 Low-density Palaeolithic/Mesolithic sites

Areas such as Le Pulec and Le Hocq have produced occasional Palaeolithic finds on the beach that presumably derive from the sediments once exposed in the cliffs adjacent to the beach. In the case of Le Hocq, these are likely to include sediments associated with some of the higher raised beaches where they intersect with the modern coastline. Presently, little is known of these finds and the sediments from which they derive.

2.6.4 Neolithic sites

As with the Palaeolithic/Mesolithic archaeology, big sites dominate the narrative for the Neolithic. These big sites are the megalithic monuments, the largest of which is La Hougue Bie. This site was excavated most recently by Mark Patton and forms the centrepiece of the Island's prehistoric archaeology alongside the recently discovered late Prehistoric Grouville hoard. While some of these sites rest on bedrock or the loess of the interior, such as La Hougue Bie, La Pouquelaye de Faldouet and La Sergente, and are associated with the modern landscape, others, such as the collection of stones at Les Blanches Banques (Broken and Little Menhir, the Ossuary and the Great Menhir) and the structures at Ville-és-Nouaux, are buried within or beneath sands associated with an older Holocene landscape.

Non-ritual sites are significantly rarer in Jersey and until recently they were little understood. A possible hearth structure was located buried beneath 1.5 m of colluvium in St Clement, while more extensive evidence of occupation and domestic rubbish has recently been excavated on the edge of the Simon Sand quarry in St Ouen's Bay. This area of western Jersey possibly contains an extensive buried late Prehistoric landscape, but a similar buried landscape also exists in the centre of the Island at St Aubin's Bay, where the monuments of Ville-és-Nouaux and the Gasworks site suggest that a similar such landscape is present.

2.6.5 Landscapes

What links together the archaeological sites discovered across Jersey is the landscapes they are associated with. These range from the large Ice Age landscapes that include the seabed of the territorial waters of the Island to the landscapes preserved within the bays and coves of the Island, such as those in the St Ouen's and St Aubin's bays. These landscapes (or topographic templates) on which, or within which, humans lived and left their impact are variably preserved across the Island and it is the traces of these systems that link together our archaeological archive. Sometimes these topographic templates are coincident with the modern ground surface (e.g., the late Prehistoric landscape associated with Neolithic monuments such as La Hougue Bie), while at other times the same late Prehistoric landscape may be buried beneath the ground (e.g., beneath up to 2 m of sand in St Ouen's Bay or deeply buried by colluvium in the inland valleys). At other localities (e.g., Les Varines), a number of landscapes of different ages may be preserved beneath the ground, stacked one above the other. Our landscapes or topographic templates therefore create the framework within which the traces of human activity reside.

Understanding the three-dimensional nature of these landscapes is important to our understanding of the archaeology because of the following:

1. It enables us to understand the nature and way in which the archaeological site or collection of artefacts operated in its contemporary landscape.
2. It enables us to understand the taphonomic history of the artefacts and ecofacts associated with the site.
3. It allows us to understand how artefacts/ecofacts might be distributed away from the site through natural processes.
4. It allows us to predict where archaeological material may be buried in subsurface contexts.

Consequently, it is important to understand these landscapes across the whole of the Island and not just as sequences at points across the landscape, which causes the dimensionality of the sequence to be unappreciated.

3 Evaluating Jersey's Geodiversity

The methods of site selection employed by the project are informed by approaches for geodiversity characterisation that have been developed and employed internationally since the 1990s (see Brilha, 2016 for a recent summary). The valuation methods and formats for data capture follow standard practices developed by the British Geological Survey and employed in 12 previous geodiversity audits led over the last 15 years.

The methods (discussed below) are also comparable to those used to identify sites for the GCR (Ellis, 1996) and RIGS (http://wiki.geoconservationuk.org.uk/index.php?title=RIGS_Handbook) networks and involve three key stages:

- Stage 1: literature review, data acquisition and consultation with local experts
- Stage 2: field-based data collection
- Stage 3: review and documentation.

3.1 STAGE 1 – DESK STUDY

The starting point of a geodiversity audit is the collection of information to help inform the site selection process. Foremost in this is a detailed desk study of the available literature, including scientific papers, books, reports and guides (including web-based resources), and consultation with experienced geologists working in the region. Key literature and resources reviewed for this audit include the following:

- BGS Jersey 1:25 000 geological map (1982) and Classical Areas of British Geology, Jersey (1989)
- The Geology of Jersey, Channel Islands – Geologists Association Guide No. 41 (2003)
- Jersey's Geological Heritage – Sites of Special Interest – Nichols & Blampied, States of Jersey (2016)
- Société Jersiaise website (https://societe-jersiaise.org)
- Natural Sites of Special Interest (SSIs) at www.gov.je
- Sites that are part of the Jersey Geology Trail, listed at http://www.jerseygeologytrail.net/
- Les Minquiers – A Natural History (2016)

Data from previous geodiversity audits have also been incorporated, particularly data from Davis (1996), who led a study that identified geological localities, identified by J Renouf, for consideration as SSIs. The current study has also reviewed approximately 150 documents and websites to help identify and document sites; a list of these documents and websites is provided in the reference section of this report.

Consultation with local geologists and archaeologists and experienced community participants was undertaken to capture 'active' knowledge and prioritise sites for review and field evaluation. This 'active' knowledge is a critical part of the geodiversity audit, providing valuable and detailed information for key features of importance and identifying specific research publications highlighting the scientific significance of many potential sites. Local knowledge is also valuable in helping to identify access routes to sites and potential safety factors. Matthew Pope and Martin Bates have also provided specialist input, especially in the areas of archaeology and Quaternary geology.

Topographic maps in the form of detailed digital vector data and ArcGIS shape files illustrating the distribution of existing SSIs and buildings of historical importance were supplied by Jersey Heritage. These data informed the delineation of site boundaries and the evaluation of the relationships between the geodiversity sites (both existing SSIs and potential new sites) and other conservation areas.

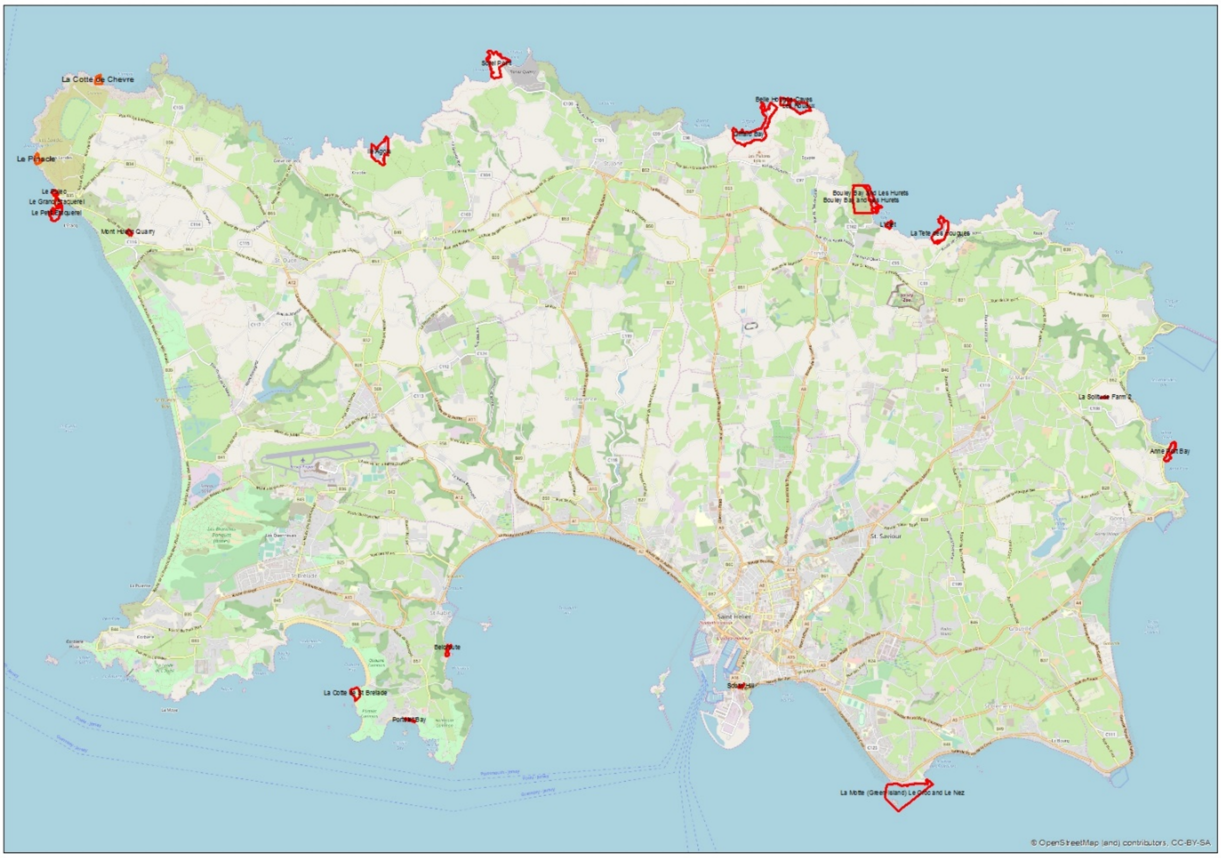


Figure 11 **Existing Geological SSIs.**

3.2 STAGE 2 – FIELD-BASED DATA COLLECTION

The information from the desk study and consultation with local geologists informed the selection of potential sites of interest. This list formed the basis of the field campaign, which involved making site visits for the data capture in order to provide descriptions and subsequent evaluations of the sites.

A team of six BGS geologists visited Jersey for two main fieldwork sessions (21–28 September and 12–19 October 2019) and one earlier scoping visit (11–13 June 2019). The field visits were undertaken with the following objectives:

- Assess the quality of the exposure or feature at the site, i.e., determine whether the key features are visible and accessible.
- Make new observations of the visible features at the site.
- Collect field photographs of the site.
- Assess the site's context, condition and safety with respect to site access.

Field observations were captured on ruggedized tablet PCs using GPS-enabled BGS SIGMA mobile tools for ESRI ArcGIS[2]. Field visits and data capture were informed by the use of digital topographic maps, aerial photograph imagery and digital geological maps, with tools for the in-field visualisation of these datasets provided by the SIGMA mobile application and tools.

[2] https://www.bgs.ac.uk/research/sigma/home.html

3.3 STAGE 3 – REVIEW AND DOCUMENTATION

Following the data capture phase, information, including descriptive and scientific details along with photographs, was compiled in detailed site reports. Due to the large number of sites, and the comprehensive nature of the documentation process, a prioritisation exercise was required to identify the most significant sites of interest for the preparation of detailed site reports. This prioritisation was based on a systematic evaluation of the geoscientific merit of each site; further details are provided in the next section.

Full site reports have been compiled for key sites identified by their high geoscientific merit, i.e., those considered to provide the best examples of geodiversity in Jersey. These include existing SSIs and a number of proposed new SSIs (see Section 0 for the full list). For sites considered to have lower geoscientific merit, summary descriptions are provided to document their key features, but full site reports have not been compiled. The full site report includes comprehensive information on the geographical, geological and geoheritage aspects of the site and the site's geoscientific merit, condition and access. Each site report includes the following descriptive information.

General Information
A record of the site's geographical location, type, ownership and current use (Table 3).

Stratigraphy and Rock Types

The 'age' (chronostratigraphy), 'formation' (lithostratigraphy) and rock type (lithology) of the exposures present. Ideally, representative sections of the main formations in the region should be represented in the selected sites. Lithostratigraphic and chronostratigraphic terms follow accepted scientific practice.

Site Description
A narrative description of the features that the site has been selected for, along with a short description of other features of interest that may be present at the site. Site descriptions follow standard terminologies used in BGS geodiversity auditing (Table 4).

Access and Safety
Safe access is a key factor for sites, particularly where the potential value for geotourism is an important consideration for the audit. This includes road access and parking, trackways and paths, the safety of access, the safety and condition of the exposure, the current condition of access routes and paths, current conflicting activities that may restrict access, restricting conditions and the nature of the exposure.

The information collated is descriptive and for general guidance only. The conditions of access may be subject to change due to land use or land management activities, climatic conditions and natural processes such as weathering, coastal erosion or landslides. It should be noted that many sites in Jersey are coastal and are therefore affected by tides, waves and exposed weather conditions; specific considerations for visiting coastal sites may be required for site access, and field leaders and teachers should prepare appropriate risk assessments for specific activities when required. Investment in improvements to access may enhance a site's potential and may be considered in relation to development opportunities at key sites.

Cultural, Heritage and Economic Value
These criteria are taken from the UK RIGS system and include any known links and important associations with the literary, cultural, aesthetic and historical aspects of geodiversity; they also include information about any geological materials that have been exploited commercially in the past.

Historic, Archaeological and Literary Associations
These criteria recognise the cultural and heritage associations of a site, including links with literary or historical events, and people relevant to the history of Earth science.

Aesthetic Landscape
These criteria reflect the aesthetic qualities of the landscape, or the setting for the site. Aesthetic sites demonstrate the importance of geology for understanding and appreciating some of our cherished landscapes and scenery (UK RIGS, 2000). The attractive/aesthetic qualities may have a particular association with the geodiversity context or may be peripheral, but they are nonetheless of value for public interest and geotourism. In the UK, areas known for their aesthetic qualities are recognised as National Scenic Areas or National Parks.

History of Earth Science
This criterion recognises the significance of the site for the history of Earth science, including its role in the development of significant geoscience concepts and links to the work of notable geologists.

Economic Geology
Many geological sites have economic associations with the past and present extraction of geological resources that are used as raw materials, the subsequent processing of these materials or the reclamation and later use of the site. Examples may include the following:

- the past/present extraction of coal, sand and gravel, building stone, metallic ores
- processing plants such as furnaces that are also likely to be sites of importance for industrial archaeology
- land reclamation projects where the geological aspects are significant.

Current Site Usage
A record of how the site is presently used by the community and for education.

In addition to descriptive information, the site report provides summary evaluations of a site's condition, or fragility, in relation to a range of potential risk factors that includes both natural processes and human activities; it also includes suggestions for the potential uses of the site in relation to its suitability for public access and education.

Site Information	A short introduction to the site
Grid Reference	Locations of the midpoint, west end and east end of the site. These are expressed in decimal metres and decimal latitude and longitude with respect to the Jersey Transverse Mercator (Authority ID is EPSG:3109) using a projection system that matches the system used by Jersey Heritage.
Site Type	Selected from standard options defined by BGS geodiversity database of terms (see Table 4)
Site Ownership	Provided by Jersey Heritage
Current Use	Selected from standard options defined by BGS geodiversity database of terms (see Table 4)
Field Surveyors	The BGS staff who visited and documented the site
Current Geological Designations	Indication of the existing SSI designation
Date Visited	The date of the site visit provides context to the observations, as the features available will change with time due to the growth of vegetation or development, for example.
Other Known Designations	From a list of biological, landscape and cultural designations supplied by Jersey Heritage
Site Map	Map of the site with suggested boundaries. This also includes boundaries supplied by Jersey Heritage for Ecological and Building Heritage sites.

Table 3 **General information captured in full site reports**

Site Type	
NATURAL SECTION	Natural outcrop of one or more geological features forming a linear exposure (river section, cliff face, shoreline, etc.)
NATURAL EXPOSURE	Natural outcrop of geological feature
NATURAL LANDFORM	Constructional or erosional geomorphological feature (valley, crevasse, dune, all Quaternary features, etc.)
NATURAL VIEW	Collection of geological features forming a landscape overview interpretation
ARTIFICIAL MINE WORKINGS	Feature produced by mineral/coal workings (adit, spoil, hush, etc.)
ARTIFICIAL QUARRY WORKS	Feature produced by stone/aggregate workings (quarry, pit, waste dumps, etc.)
ARTIFICIAL SECTION	Section exposure created artificially by work to construct a road, track, path, etc.
ARTIFICIAL EXCAVATION	Artificially created exposure (excavation – not related to any of the above)
NOT APPLICABLE	Not applicable
NATURAL GEOLOGICAL SAMPLE NOT IN SITU	Natural geological sample not *in situ*
MANMADE ARTEFACT	Manmade artefact
Current Use	
IN CURRENT USE	Feature still used for primary purpose (working quarry, etc.) as defined by the FEATURE criteria
DISUSED	Feature no longer used for primary purpose and has no other current use
OPEN COUNTRY	Feature on publicly accessible natural countryside with no unique use (mountains, National Park land, etc.)
PRIVATE COUNTRY	Feature is on privately owned, natural countryside with limited/no public access (estate land, etc.)
AGRICULTURAL LAND	Feature is used for or forms part of land used for agricultural purposes (farm fields, grazing areas, etc.)
DOMESTIC LAND	Feature falls within the limits of private land associated with dwellings (gardens, stately home grounds, etc.)
URBAN	Feature is on publicly accessible land (but not recreational land) within the urban limits (allotments, road verges, etc.)
RECREATIONAL LAND	Feature is on land specifically designed or modified for recreational uses (parks, picnic areas, etc.)
MILITARY LAND	Feature is on MOD land or land used for military purposes
INDUSTRIAL LAND	Feature is on land used for industrial purposes (including waste land forming part of / owned by an industrial complex)
DISPOSAL USE	Feature is used or is on land used for waste disposal (quarries now used as landfills, etc.)
NOT APPLICABLE	Not applicable

Table 4 **Definitions of standard terms used in the site descriptions**

3.4 CRITERIA FOR SITE EVALUATION

A key objective of the geodiversity audit for Jersey is to ensure the comprehensive representation of Jersey's geological history within the suite of sites comprising the SSI network (through the identification and recommendation of potential new sites). A second objective set within this context is to identify opportunities to increase geotourism and public engagement at existing SSIs and new proposed sites.

The site evaluation process and criteria form a critical step in the selection of potential sites for inclusion in an expanded SSI network. The criteria used in this study are based on recognised approaches for geodiversity and geoheritage site evaluation that have been developed since the 1980s (e.g., Brilha, 2016; Wimbledon *et al.*, 1995 and used by the British Geological Survey in geodiversity audits to inform site designation and recognition in UK planning contexts (e.g., Whitbread *et al.,* 2015). These approaches have been applied with adaptations for the particular requirements of this audit.

The primary criteria for site characterisation are the geoscientific merit, which relates to the intrinsic geological attributes of the site, and the contribution of the site to scientific understanding. In the case of the Jersey audit, the geoscientific merit is evaluated within the context of the site's scientific contribution to the understanding of Jersey's geological history. This includes the following topics: (1) the Cadomian terrane and the wider plate-tectonic and crustal accretion processes occurring during this period; (2) the climatic and landscape evolution of Northern Europe from the Quaternary to recent times; (3) prehistoric sites preserving evidence related to the record of the peopling and depopulation of the region during the Pleistocene and the adaptation to Quaternary climatic and environmental change.

The geoscientific merit criterion, evaluated under the term 'Rarity', reflects the significance of the site with respect to key aspects of the regional geological history. It includes consideration of the representativeness of the site of key elements of this history and whether it represents a unique occurrence relative to the wider region of the Cadomian terrane and/or the northern European region.

Although the bedrock and Quaternary geological contexts are quite distinct in their scientific context, many sites display features and attributes related to both contexts, and associations between bedrock materials and Quaternary processes can highlight important relationships in landscape evolution. Thus, a single Rarity value is given for each site. However, for each site the 'primary interest feature(s)' are stated, and the geoscientific merit criterion is classified with respect to these. Further detail concerning the particular context for the classification of rarity for a given site is provided in a summary description of the key geoscientific features. An additional factor noted as part of the geoscientific merit of a site is the history of scientific study associated with the site, in the form of published literature about the site, the inclusion of the site in field guides and the association of the site with sample materials held in collections.

The 'Quality' criterion reflects the potential value of the site for public education and tourism, or its 'presentation value'. The Quality criterion is based on an assessment of the visibility of the key geological features of the site and the degree to which access is fundamentally restricted by natural or human factors.

The grading scheme for the Rarity and Quality factors is as follows:

Rarity

International – The site is representative of key elements of the geological history of the Cadomian terrane and/or the Quaternary history of Northern Europe and provides a particularly complete/unique/valuable scientific record.

Regional – The site is representative of aspects of the geological history of the Cadomian terrane and/or the Quaternary history of Northern Europe and provides a substantial/unique contribution to the understanding of Jersey's geological history.

Local (e.g., for a local school or community group) – The site provides examples of geological and geomorphological features of interest, with a limited contribution to the understanding of Jersey's geological history.

Quality

Excellent – The site presents clear exposures of key features, including, e.g., continuous sequences, significant horizons and undisturbed natural landforms, with no restrictions on visibility or access.

Good – The site presents exposed features but may be affected by some natural or human degradation and/or minor issues with visibility and access.

Moderately Good – The site presents exposed features that are affected by some natural or human degradation and/or moderate issues with visibility and access.

3.5 DEFINING THE SITE BOUNDARY

The site boundary defines the total area considered to be integral to the geodiversity site (Whitbread *et al*., 2015). The site boundary is thus consistent with a proposed protection zone that is necessary to maintain the integrity of the geodiversity site. The site boundary may encompass one or a number of areas of exposed geological features, including rock outcrops, landforms and any adjacent geologically significant areas considered integral to the site due to landscape and access considerations.

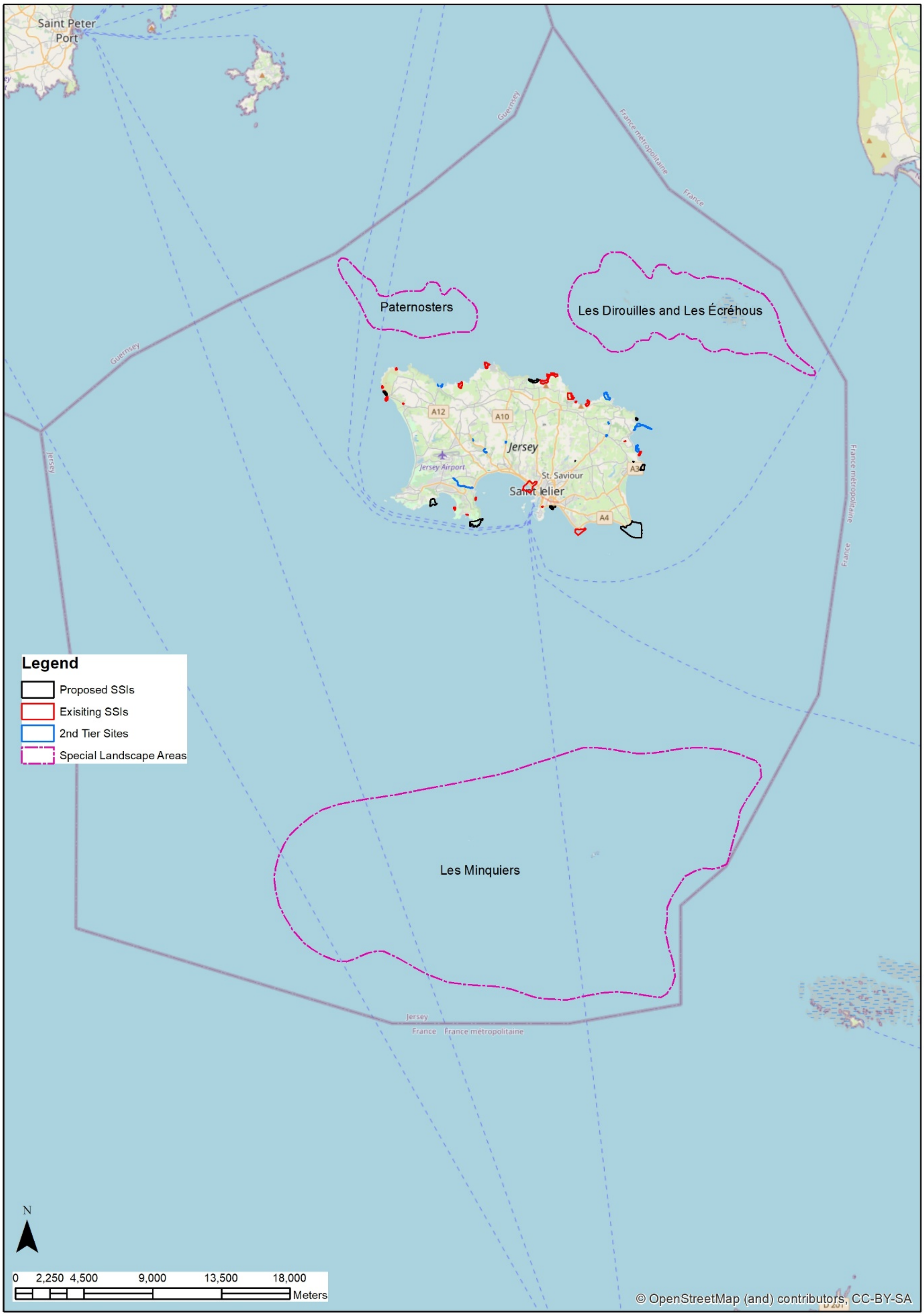
The site boundaries have been defined following field visits and informed by topographic maps and aerial photographs available for the area. In coastal areas, the site boundaries normally extend offshore to the mean low water springs. The boundaries have been digitised using the ESRI Arc Shapefile format and are supplied with this report. The Shapefile should be regarded as providing the definitive site boundary for reference purposes.

4 Recommended Sites

This review has revisited all the accessible, existing Geological SSIs in order to review their geological features and safety issues as well as their potential for use as local amenities or for education and research. These sites have all been documented using the procedures described in Section 3. In addition, a number of new sites are recommended for consideration as SSIs and others are proposed as second-tier sites that can support the SSIs.

In addition, a number of proposed Special Landscape Areas (SLAs), which contain a wealth of sites, are discussed.

- **Feature-scale sites.** These sites would include the existing Geological SSIs and those recommended by this study, and they would be protected through the current legislation. A second tier of sites is also recommended.
- **Special Landscape Areas (SLAs).** These sites are intended to extend over large areas of landscape. These areas could be protected and managed in a similar way to Areas of Outstanding Natural Beauty (AONBs) in the UK or National Parks. A good example of this would be the extensive area of reefs in the south-east of Jersey.
- **Prehistoric Landscape Zones (PLZs).** These are mapped areas of landscape that preserve extensive outcrops and subcrops of unconsolidated, Quaternary-aged deposits with archaeological and/or palaeoenvironmental potential.



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Figure 12 **Distribution of existing and proposed Geological SSIs and prehistoric sites.**

4.1 FEATURE-SCALE SITES

4.1.1 SSIs reviewed and new sites recommended by this study

Site Name	Recommended conservation status	Primary interest
Petit Étacquerel	Existing SSI	*Jersey Shale Formation*
Grand Étacquerel	Existing SSI	*Jersey Shale Formation*
St Peter's Valley	Proposed SSI	*Jersey Shale Formation*
Giffard Bay	Existing SSI	Volcanics
Les Rouaux	Existing SSI	Volcanics
Les Hurets, Bouley Bay	Existing SSI	Volcanics
Anne Port	Existing SSI	Volcanics
Dolmen de Faldouet	Proposed SSI	Volcanics
Mont Sohier	Proposed SSI	Volcanics
Bonne Nuit	Proposed SSI	Volcanics
Havre de Fer / L'Archirondel Bay	2nd Tier	Volcanics
St Helier Syncline	2nd Tier	Volcanics
Mont Huelin Quarry	Existing SSI	Intrusive igneous and *Jersey Shale Formation*
Le Pulec	Existing SSI	Intrusive igneous and *Jersey Shale Formation*
Le Pinacle	Existing SSI	Intrusive igneous
Sorel Point	Existing SSI	Intrusive igneous
La Motte, Le Nez and Le Croc	Existing SSI	Intrusive igneous
Noirmont	Proposed SSI	Intrusive igneous
La Rocque	Proposed SSI	Intrusive igneous
The Dicq to The Lido (Havre des Pas)	Proposed SSI	Intrusive igneous
Beauport and Fiquet	Proposed SSI	Intrusive igneous
Grève de Lecq	2nd Tier	Intrusive igneous
St Aubin, railway cutting	2nd Tier	Intrusive igneous and *Jersey Shale Formation*
Grève au Lançon	2nd Tier	Intrusive igneous
St Lawrence's Church	2nd Tier	Intrusive igneous
St Martin's Church and La Pollotterie	2nd Tier	Intrusive igneous
St Catherine's Breakwater, Quarry and Bay	2nd Tier	Intrusive igneous
La Tête des Hougues	Existing SSI	*Rozel Conglomerate Formation*
La Solitude Farm	Existing SSI	*Rozel Conglomerate Formation*
Tour de Rozel	2nd Tier	Rozel Conglomerate
Belcroute	Existing SSI	Quaternary
Portelet	Existing SSI	Quaternary
L'Islet, Bouley Bay	Existing SSI	Quaternary
Fliquet	Proposed SSI	Quaternary
South Hill	Existing SSI	Quaternary
Belle Hougue Caves I and II	Existing SSI	Prehistoric
La Cotte à la Chèvre	Existing SSI	Prehistoric
Crabbé and Ile Agois,	Existing SSI	Prehistoric and Quaternary
La Cotte de St Brelade	Existing SSI	Prehistoric
St Ouen's Bay Peat Beds	Existing SSI	Prehistoric
Les Varines	Proposed SSI	Prehistoric
Petit Portelet and Mont Orgueil Castle and Headland	Proposed SSI	Prehistoric and intrusive igneous

Table 5 **Existing and recommended SSIs and 2nd Tier sites**

4.1.2 Summaries of the existing and proposed SSIs

Please see Sections 7 and 8 for full reports.

Primary interest: Jersey Shale Formation

Petit Etacquerel, SSI
This site comprises an intertidal area of outcrops around the headland at L'Etacq in the northern part of St Ouen's Bay. The bedrock is part of the *Jersey Shale Formation*, which here contains a range of internal structures that demonstrate its deposition as turbidites in the lower part of the middle to outer sections of a submarine fan that formed roughly 587 million years ago. Sediments deposited in other parts of this fan can be seen at Grand Étacquerel and at sites in St Peter's Valley.

Grand Etacquerel, SSI
This site comprises much of the headland at L'Etacq in the northern part of St Ouen's Bay. The bedrock is part of the *Jersey Shale Formation*, which here contains a range of internal structures that demonstrate its deposition as turbidites in the outer parts of a submarine fan, which formed roughly 587 million years ago. Sediments deposited in other parts of this fan can be seen at Petit EÉtacquerel and at sites in St Peter's Valley.

St Peter's Valley, proposed SSI
In St Peter's Valley, between Quetivel Mill and Gargate Mill, there are a number of small quarries and road cuttings in the *Jersey Shale Formation*. Closer to Quetivel Mill, the rocks contain a range of internal structures that indicate deposition within the middle parts of a submarine fan. In a small trackside cutting behind Gargate Mill, a conglomerate can be seen; it is interpreted to have been deposited in canyons or the inner parts of the submarine fan.

Primary interest: Jersey Volcanic Group

Giffard Bay, SSI
Giffard Bay is a coastal site located in the north of Jersey, where cliffs, promontories and intertidal reefs expose a rock sequence of predominantly extrusive volcanic rocks of the Bouley Rhyolite, St John's Rhyolite and St Saviour's Andesite formations. A faulted contact between the *Jersey Shale Formation* and the Bouley Rhyolite Formation is exposed in the south-east corner of the bay. In the middle of the bay, the Bouley Rhyolite Formation is intruded by a number of lamprophyre dykes. Rhyolite and andesite lavas, tuffs, agglomerates and conglomerates of the St Saviour's Andesite Formation are exposed in a complex series of fault-bound slices in the cliffs and promontories between the Long Echet and the south-east corner of Giffard Bay. Pebbly beach gravel of the 8 m raised beach is overlain by >8 m of boulder head in cliffs behind the rock promontory backing the middle part of the site. Great care needs to be taken in accessing this site due to risk from high tides and uneven ground.

Les Rouaux, SSI
Les Rouaux is an existing SSI on Jersey's north coast, where a number of geological features are exposed on the 8 m wave-cut bedrock platform. The shore platform is very difficult and dangerous to access directly from the coastal path, but the headland gives a panoramic view of Les Rouaux Fault. This view shows that rocks of the Belle Hougue igneous complex are clearly faulted against the *Jersey Shale Formation* and the St Saviour's Andesite Formation. Sedimentary structures and deformation features have been recorded within the *Jersey Shale Formation*. This formation transitions upwards into the volcanic rocks of the St Saviour's Andesite Formation, which can be examined in exposures along the clifftop path.

Les Hurets, Bouley Bay, SSI
Les Hurets, Bouley Bay is an existing SSI on Jersey's north coast containing ignimbrites and rhyolites of the Bouley Rhyolite Formation. Large fallen blocks on the foreshore at the western end of Bouley Bay contain impressive examples of spherulites showing a range of sizes and forms; they can be seen *in situ* in small exposures on the path to Les Hurets Old Guardhouse and

around the guardhouse itself. The 8 m raised beach, resting on gravel head and overlain by bouldery head, can be seen at the back of the bay.

Anne Port, SSI
Located on the east coast of Jersey, Anne Port Bay (referred to 'Jersey's Giant's Causeway') is an existing SSI due to the presence of well-developed columnar jointing within the Bouley Rhyolite Formation (U-Pb zircon age of 583 ± 3 Ma; Miller *et al.*, 2001). The site also displays excellent exposures of the St John's Rhyolite Formation, a sequence of rhyolites and agglomerates that contain a range of igneous textures, including flattened pumice and volcanic glass shards as well as flow structures. The volcanic rocks are intruded by a number of composite basic dykes. The Bouley and St John's rhyolite formations may represent the eruptive equivalents of the South-west and *South-east igneous complex*es, which were emplaced during the Cadomian Orogeny. In the sea cliffs, the igneous bedrock is directly overlain by a much younger boulder head deposit. Although it is restricted by tides, the site is much safer to walk across than those at Giffard Bay, and it is more accessible than the Les Rouaux and Les Hurets, Bouley Bay sites; however, it does show different features, and the stratigraphical relationships between the rock units and some of their features are more clearly exposed than at the other sites. The columnar-jointed Anne Port Rhyolite (part of the Bouley Rhyolite Formation) at Anne Port was sampled by Miller *et al.* (2001), making this site of interest to professional Earth scientists and the public alike.

Dolmen de Faldouet, proposed SSI
The Dolmen de Faldouet (or La Pouquelaye de Faldouet) site is located on a hill inland of Anne Port Bay on Jersey's east coast. It is primarily an archaeological site featuring one of the Island's most impressive passage graves from the Neolithic Period. The geological interest lies in the different rock types and the origin of the stones used to construct this Neolithic structure, in particular a single massive capstone of autobrecciated flow-banded rhyolite that covers the circular burial chamber at the end of the stone-lined passage.

Mont Sohier, proposed SSI
The Mont Sohier site provides a rare inland exposure of the St Saviour's Andesite Formation, which displays pillow-like structures in a roadside cutting near Highfield Vineries. Although they are heavily weathered, 'pillows' measuring 10 cm in size can been seen in the andesite lavas, which display spheroidal weathering. The andesite lavas may represent the eruptive equivalent of the South-west and *South-east igneous complex*es, which were emplaced during the Cadomian Orogeny. The site is important because of the presence of possible pillows within the andesite lavas, which indicate eruption into a body of water. Gravelly head with angular clasts of andesite is exposed beneath loessic soil in an adjacent cutting.

Bonne Nuit, proposed SSI
Bonne Nuit is a north-facing coastal site, bounded to the east and west by rocky headlands and backed to the south by a cliff section cut into Quaternary deposits; part of this section includes the 8 m raised shoreline in the area. The head deposits at the site display evidence of evolving palaeoenvironments, with a rapid, dynamic change recorded by possible shallow lake or lagoon sediments, which were later buried by a large debris fan. The disturbance of the lake sediments shows that this burial may have taken place in a single, large event. The fan deposits locally directly overlie the pebbly gravel of the 8 m raised beach. Iron-cemented gravel plastered over foreshore exposures of the Bonne Nuit Ignimbrite are thought to represent a remnant of the raised beach, indicating that it extends from near the present sea level up to *c.* 8 m above mean sea level.
Exposures of volcaniclastic rocks of the St John's Rhyolite Formation occur at the La Crête headland and in foreshore reefs in the eastern and middle parts of the site. The formation comprises a complex sequence of rhyolitic ignimbrites, andesitic agglomerates and tuffs, which display a wide variety of igneous textures and extrusive contacts. These features indicate that at least parts of the sequence were emplaced either in a subaqueous environment or on top of water-saturated sediments. The formation shows a transition from rhyolitic volcanic activity, typified by the Bonne Nuit Ignimbrite, through andesitic pyroclastic rocks and then back into rhyolitic activity, with the emplacement of the Frémont Ignimbrite. They therefore provide crucial evidence of the evolving volcanic environment during the eruption of the *Jersey Volcanic Group*.

Primary interest: Intrusive igneous

Mont Huelin Quarry, SSI
This site is a quarry on La Route de l'Etacq, to the north of the hamlet of Le Haut de l'Etacq. The *Jersey Shale Formation* is exposed here where it is in contact with the *North-west igneous complex*, and it is altered by the heat associated with the intrusion of the granite. The *Jersey Shale Formation* was deposited as turbidites in a submarine fan that formed roughly 587 million years ago and was folded and weakly metamorphosed during the Cadomian Orogeny. The *North-west igneous complex* was emplaced in the Ordovician Period.

Le Pulec, SSI and proposed extension
Le Pulec is the best place in Jersey to observe the contact between a major intrusion and the 'country rock' into which it was emplaced. The site also presents good examples of many geological features that typically form around such contacts. The site consists of intertidal outcrops on the north side of Le Pulec, a small bay towards the north end of the west coast of Jersey. The bedrock comprises a turbidite succession in the *Jersey Shale Formation* and the granite of the *North-west igneous complex*. This site is equally important for understanding past sea levels across Jersey and the rest of the Channel Islands.

Le Pinacle, SSI
The site is a section of dramatic cliff-lined coast near the north end of the west coast of Jersey that includes The Pinnacle (also known as Le Pinacle), a large and visually striking 'fossil stack'. This well-known geomorphological structure is the main feature of interest, but the site includes good outcrops of St Mary's granite (the largest component of the *North-west igneous complex*), perhaps the best examples in Jersey of igneous sills, good examples of wave-cut notches formed in the geologically recent past when the relative sea level was higher than it is now and some important prehistoric structures. A significant sequence of Quaternary head lies preserved on the landward side of Le Pinacle: this preserves significant prehistoric and Romano-Gallic archaeology at the surface as well as prehistoric artefacts within the deeper sediments themselves.

Sorel Point, SSI
Sorel Point is a steep, craggy headland on the north coast of Jersey, where a lithologically diverse part of the *North-west igneous complex* is exposed. The site provides a window into the processes and lithological associations that can occur in dynamic magma chambers, and it has a long association with the development of ideas about how coeval magmas interact and evolve; therefore, it is arguably of international importance. However, scrambling on steep, rocky ground is required to reach many of the best exposures.

La Motte, Le Nez and Le Croc, SSI
The La Motte, Le Nez and Le Croc site, near the south-east extremity of Jersey, comprises a small tidal island (La Motte, or Green Island) and intertidal exposures extending discontinuously from La Motte to the nearby rocky promontories of Le Croc and Le Nez. The bedrock is a lithologically variable part of the *South-east igneous complex*. Each of three main outcrops in the site displays a distinct range of igneous features that collectively present a window into a dynamically evolving magma chamber. The site includes good examples of the Jersey Main Dyke Swarm, and both La Motte and Le Nez provide excellent viewpoints over the largest intertidal rock platform on the Jersey coast.

The top surface of the island, which is several metres above mean high water springs(MHWS), is underlain by 0.25 m of raised beach gravel, which is succeeded by up to 4 m of loess and capped by *c.* 0.3 m of blown sand and soil. The island has significant archaeological importance, including cist graves. These were thought to be Neolithic, but it is now thought that these date to the 10th and 11th centuries AD.

Noirmont, proposed SSI
The site is a craggy headland at Noirmont on the south coast of Jersey. A wide range of intrusive igneous rocks are the main features of interest. The bedrock is primarily Corbière granite, the most extensive component of the *South-west igneous complex*. The site includes excellent

exposures of typical Corbière granite, dolerite dykes of the Jersey Main Dyke Swarm and a late mica-lamprophyre dyke. The site also presents exposures of Quaternary deposits.

La Rocque, proposed SSI
The site encompasses part of the intertidal zone around La Rocque Harbour, at the south-east extremity of mainland Jersey. The bedrock is La Rocque granite of the *South-east igneous complex*. The site includes perhaps the best exposures of La Rocque granite (the most extensive and youngest major component of the *South-east igneous complex*) in any of the Jersey geodiversity sites, and some of the best examples in Jersey of features found in fluid-rich magmas (coarse pegmatitic granite and miarolytic cavities). Slipways, breakwaters and walls within the site present a good display of Jersey igneous rocks used as building stones. The site also provides an excellent viewpoint over the largest intertidal rock platform (or reef) on the Jersey coast.

The Dicq to The Lido (Havre des Pas), proposed SSI
The site, on the south coast of Jersey at St Helier, encompasses the intertidal zone between Le Dicq in the east and Havre des Pas Pier in the west. The bedrock is a lithologically variable part of the *South-east igneous complex*. The key geological features are contained in three separate outcrops within the intertidal zone. A large outcrop at Le Dicq contains the best exposures of Dicq granite in any of the Jersey geodiversity sites. Low-lying exposures beside The Lido include a contact between Dicq granite and another granite body in the *South-east igneous complex*, possibly Longueville granite. Another large outcrop beneath Havre des Pas Pier presents spectacular examples of two types of magma interaction (magmatic brecciation and magma mingling) in multiple generations of diorite and granite; the resulting textures are clear evidence of a dynamic magma environment. Basalt dykes of the Jersey Main Dyke Swarm cut the outcrops at The Dicq and The Lido. Pleistocene sediments are also suspected to exist preserved under modern beach materials here, explaining the well-preserved Middle Palaeolithic tools found in this area.

Beauport and Fiquet, proposed SSI
The site comprises the two adjoining embayments of Beauport and Fiquet. Apart from the extreme south-western corner of Fiquet, the bedrock is of the Beauport aplogranite type from the concentrically zoned *South-west igneous complex*, of which it forms the innermost zone. The rocks are well exposed along the intertidal platforms and in the surrounding castellated cliffs. Of major interest are the many geomorphological features of Quaternary age, including erosional platforms, deep gullies often backed by caves, raised beach deposits overlain by head, including loess lenses, and blown sand. There are several boulder fields on the intertidal platform in Fiquet, and these are notable and unique in Jersey for the extent of the evidence they provide of extensive artisanal working for dimension stone from the seventeenth century to the early nineteenth century.

Primary interest: Rozel Conglomerate

La Tête des Hougues, SSI
This site is within a small bay to the east of the L'Étacquerel Fort at La Tête des Hougues in the south-east corner of Bouley Bay in north-east Jersey. In this bay, the *Rozel Conglomerate Formation* unconformably overlies the Bouley Rhyolite Formation. The rhyolites comprise flow-banded lavas and ignimbrites, which often have spherulitic textures. The top of the formation has an irregular, sometimes deeply eroded surface that includes a fossil scree deposit. The overlying *Rozel Conglomerate Formation* comprises mainly coarse conglomerates with some sandstones and mudstones, which were deposited in alluvial fans with a source area to the north of Jersey.

La Solitude Farm, SSI
This site is a roadside cutting along the Rue de la Solitude, west of St Catherine's Bay. An atypical part of the *Rozel Conglomerate Formation* is exposed here: it comprises a weathered conglomerate with lithic sandstone lenses that is thought to represent a palaeo-weathered surface on an abandoned segment of an alluvial fan. The mudstone bands seen here are thought to have been deposited in a marginal lake; this is rare throughout the rest of the formation. More typical

examples of the formation can be seen at the La Tête des Hougues SSI and the quarries at St Catherine's Breakwater and Tour de Rozel. The alluvial fan has a source area to the north of Jersey and is a great example of a river developed before the existence of land plants, whose evolution and associated soil development had a profound impact on the morphology of river systems.

Primary interest: Quaternary

Belcroute, SSI
The Belcroute Bay site consists of a series of small inlets, which are separated by rocky headlands located to the south of St Aubin Harbour. The inlets are backed by cliffs that reveal sections through a sequence of Quaternary sediments. These deposits are reported to span two warm stages with high sea levels and at least two cold stages; this complex palaeoenvironmental/climate record is the primary reason that the Belcroute Bay site was designated as an SSI.

Portelet, SSI
Portelet Bay is a south-facing crescentic bay whose 70-m-long central exposed cliff section already has an SSI designation. The cliff sections are capped by blown sand deposits from the Early Devensian Period. The cliff exposure provides possibly the best exposure of Middle and Late Quaternary sediments on the Island; it is comprised of basal head deposits, including coarse marine sands, overlain by beach cobble and boulder beds, which are in turn overlain by dune sands and head that are capped by loess. The entire sequence most likely spans the period from *c.* 245 ka BP to *c.* 60 ka BP. The site is important because this sequence spans two warm stages with high sea levels and at least two cold stages.

L'Islet, Bouley Bay, SSI
The L'Islet, Bouley Bay site comprises a north-facing pebbly sandy bay with a tidal islet on its eastern side and steep-backed coves to the north. L'Islet is cut off at high tide and is a tall pinnacle of vegetated rock with good exposures of head and loess deposits. The bay is popular with tourists and locals and has a small harbour; swimming, diving and fishing are common activities year-round.

South Hill, SSI
The geology and geomorphology exposed at South Hill SSI comprises (1) a raised beach complex, which is composed of a cobble beach at 40 m on the South Hill plateau, a finer-grained marine beach at *c.* 30 m in South Hill Gardens, a range of cold stage loessic deposits bordering the Mount Bingham road below South Hill and a wave-rounded outcrop of granophyre to the south-west of the road on the corner; and (2) a lamprophyre dyke cutting the Fort Regent Granophyre. The cobble beach occupies a high-tide gully that is 6 m wide and 3 m deep; it is visible behind protective geotextile fabric at the rear of the Fisherman's Cottage. An earlier cross-section through the deposit at the top of the cutting is now concealed beneath vegetation, as is most of the lamprophyre dyke. The 40 m cobble beach is the only known cobble beach at this height in the Channel Islands and the adjacent Cotentin; no other examples currently exist in this area.

Fliquet, proposed SSI
Fliquet is a coastal site located in the north-east corner of Jersey; it contains the only known peat beds on the island that are more than 25,000 years old. The bed of compressed peat infills a shallow elongated basin cut into the *Rozel Conglomerate Formation* and generally lies preserved beneath the present-day pebble beach, although it is occasionally exposed by storms. Good intertidal exposures of the *Rozel Conglomerate Formation* are also present at the site, along with a beach cliff displaying Quaternary head deposits.

Primary interest: Prehistoric

Belle Hougue Caves I and II, SSI

Belle Hougue Caves I and II are an existing SSI on Jersey's north coast and comprise two sea caves eroded into the faulted dioritic rocks of the headlands, which feature two raised wave notches at 18 and 8 m. The 8 m notch includes a beach deposit dated to the last interglacial and archaeological finds within the Quaternary deposits inside the cave, which are unique at this height above sea level within the Channel Islands and include marine molluscs along with bones and antlers from a now-extinct dwarfed red deer. While no confirmed human artefacts have been found, it is possible that the caves were used by people during the Palaeolithic.

La Cotte à la Chvre, SSI

Not visited by BGS during this study due to difficult access. Therefore, this description is extracted from Davis (1996).

La Cotte à la Chèvre is a sea cave on the north-west coast of Jersey. The site is of particular importance, as it has been the site of historic archaeological investigations that produced worked flints and evidence of fires, assumed to be created by Palaeolithic hunters. The cave was likely developed by erosion when the sea level was higher, and it is perhaps associated with the 14 m level identified elsewhere on the island. Although historic excavations have destroyed much of the prehistoric evidence, the site remains important for teaching.

Crabbé and Ile Agois, SSI

This site comprises a *c.* 1 km section of coastal cliffs, headlands and bays from Devil's Hole to Crabbé. Wave-cut notches from remnant raised shorelines at the 8 m and 18 m levels can be observed along with a through cave known as Devil's Hole. The coastline is cut into the *North-west igneous complex*. The sea stack of Île Agois itself supports significant Iron Age and Early Medieval archaeological remains.

La Cotte de St Brelade, SSI

La Cotte de St Brelade is the most significant Quaternary site in Jersey. The site comprises a T-shaped ravine system within a granite promontory above the southern end of St Brelade's Bay, and since 1881 it has been the focus of archaeological research due to the abundant record of Palaeolithic artefacts and Pleistocene faunal remains that have been recorded at the site.

The site is internationally important. Its importance rests primarily on the time-depth of the site, which contains successive Quaternary deposits spanning over 238,000 years and consequently preserves a regionally significant record of climate and environmental change. These deposits also include a large collection of Middle Palaeolithic artefacts, butchered faunal remains and hominin fossils, which raises that importance to the highest level of significance for a site of this type. The site has been subject to severe erosion and loss over the past four decades, a process now being mitigated by engineering works funded by Jersey Heritage.

St Ouen's Bay Peat Beds, SSI

The St Ouen's Bay Peat Beds have been designated as an SSI because of the exposures of peat, which contain tree stumps, roots and tree branches. The site is principally of interest because the peat preserves fossil hoof prints, cattle bones, pottery and flint artefacts (Nichols and Blampied, 2016). The peat deposits are only infrequently exposed and are more often covered by beach sand. The peat was not exposed at the time of the BGS geodiversity audit.

Les Varines, proposed SSI

Les Varines is an internationally important site preserving a 15,000-year-old Magdalenian structure, pits, hearths, artefacts and artwork. A geophysical survey indicates that the sedimentary sequence at Les Varines is complex, and sediment accumulation in the vicinity of the site probably began during the Middle Pleistocene with the creation of coastal features during several high-sea-level events. The geomorphological context of the site is that of a cove, and there is cliff topography in which colluvium appears to be banked against a former cliff. The Upper Palaeolithic site sits on a saddle of land between a Middle Pleistocene granite cliff and a rocky outcrop that was once a sea stack. The granite features that structure the catchment are infilled with and masked by head deposits, and they are constrained to the north-east and south-west by valleys (Conneller *et al.*, 2016).

Petit Portelet and Mont Orgueil Castle and Headland, proposed SSI
Mont Orgueil Castle stands proudly on a significant granite headland at the northern end of the Royal Bay of Grouville on Jersey's east coast. The headland exists due to the resistant nature of the underlying granite to high-energy coastal erosion and weathering and has provided a place of defence and refuge since the Neolithic period. The granite belongs to the *South-east igneous complex* and is well exposed in the surrounding intertidal areas, as are a number of minor intrusions into the granite, including porphyritic microgranite, banded rhyolite, diorite and mica-lamprophyre dykes. Sections through raised beach deposits and head, which mantle the granite, can also be viewed on the eastern and northern sides of the headland.

The cliff exposes a deep sequence of Pleistocene head deposits that infills the void between the granite stack of Mont Orgueil and the fossilised cliff line that extends to the west. Within this sequence of head deposits, rounded beach gravels that have been dated to the last interglacial are present. Palaeolithic artefacts have been collected from the cliffs and beach since the beginning of the 20th century. Recent excavations in the intertidal zone have revealed that fine-grained deposits preserved within gullies in the rock geology at the base of the sequence preserve Middle Palaeolithic artefacts in fresh condition in at least two separate localities. The OSL dating of the associated sediments suggests these artefacts date to the mid-Weichselian Period.

4.1.3 2nd Tier sites

It is recognised that not all of the sites identified will achieve SSI status, although the sites may be of local significance. For the purposes of this report, SSI sites are considered to merit primary conservation status, with '2nd Tier' sites being secondary.

These secondary sites may be more accessible than or provide additional supporting scientific or educational resources relevant to the sites recommended for SSI. For example, the SSI selection process may highlight a site quoted in the literature or a site that may be the 'type locality' of a particular geological unit. This means that this particular site is the place where this particular feature was first described in the scientific literature and where the typical nature of a formation or fossil or mineral can be studied. Often these sites were identified decades ago, and they have subsequently degraded or become less accessible: while the site remains scientifically significant, other locations today may highlight the same features, be more accessible or be more easily utilised by the local community. It is these sites that are recommended to be given 2nd Tier status, and they may in time be raised to SSI status if the original locality is lost.

A good example within Jersey is La Tête des Hougues (SSI). Today, this important locality is not easy to access due to problems with it being cut off by the tide and a slippery, difficult and steep access route. The Tour de Rozel site is recommended as a 2nd Tier site, as many of the key features of the *Rozel Conglomerate Formation* are readily identified here: access to the site is easier and the site is less likely to be cut off by the tide. This study recommends that La Tête des Hougues remains an SSI, as it is the place that this formation has been described and researched in the most detail, but Tour de Rozel is a little more accessible. Together, both sites provide important information about this particular geological formation.

Havre de Fer / L'Archirondel Bay
Havre de Fer lies on Jersey's east coast and exposes rhyolites and ignimbrites of the *Bouley Rhyolite Formation*. The ignimbrites in the north of the bay locally contain bands of spherulites and some water-laid tuffs and debris flows in the exposures beneath L'Archirondel Tower. The rhyolites in the south of the bay display flow banding and columnar jointing similar to that seen at Anne Port. The rhyolites may represent the eruptive equivalent of the South-west and *South-east igneous complex*es, which were emplaced during the Cadomian Orogeny.

St Helier Syncline
A large synclinal structure approximately 1 km across is exposed on the eastern part of St Aubin's Bay and the adjacent inland area. The outcrops are defined by scattered exposures of various

volcanic lithologies, including andesites, agglomerates and tuff from the *St Saviour's Andesite Formation*. The extrusive rocks are locally cut by dolerite dykes. The volcanic sequence is exposed on the foreshore near the Victoria Marine Lake, in West Park and in former quarries that have been largely concealed by modern building development. The andesites may represent the eruptive equivalent of the South-west and *South-east igneous complex*es, which were emplaced during the Cadomian Orogeny.

St Aubin, railway cutting
The site is a *c.* 1-km-long section of the 'Railway Walk' between St Aubin and Rue du Pont Marquet in south-west Jersey. The site is underlain by both the *Jersey Shale Formation* and *South-west igneous complex*, which are exposed intermittently on both sides of the former railway cutting. The site includes (i) part of the contact zone between the *Jersey Shale Formation* and *South-west igneous complex* (the actual contact is not exposed) – these very different units are separated in age by just a few million years, demonstrating the rapidity of orogenic processes; (ii) evidence for the chilling of the igneous rocks and baking of the sedimentary rocks in the vicinity of the contact; and (iii) small landslips on the cutting walls, demonstrating the effects of recent slope instability. The site lacks outstanding geological features, but it is accessible to all.

Grève de Lecq
The site comprises intertidal exposures adjacent to and on the beach at Grève de Lecq, a small bay towards the west end of the north coast of Jersey. The bedrock is primarily *St Mary's granite* of the *North-west igneous complex*. The complex was emplaced in the Ordovician. The site includes (i) good examples of *St Mary's granite* (the most extensive component of the *North-west igneous complex*); (ii) a range of igneous features that are typical of this intrusion (and many others), including mafic enclaves, patches of pegmatitic rock, miarolytic cavities, cross-cutting sheets of aplite and a dense network of hairline, chlorite-bearing fractures with the associated hydrothermal alteration; (iii) a cross-cutting dyke of mica lamprophyre with an adjacent zone of fault rock; and (iv) a set of quartz veins that cross-cuts all the igneous rocks and in places becomes very dense (forming a stockwork). Also of note at this site is a platform (5e) that was deeply dissected during the Holocene. This extends eastward from the beach to the boundary with La Val Rouget, which also features a through cave (information from J Renouf).

Plémont / Grève au Lançhon
Plémont Beach lies within the Jersey National Park, although it does not currently have an SSI designation. The beach is a north-west-facing rocky bay, comprising a number of coves and inlets that formed due to the exploitation of natural weaknesses in the granite bedrock by wave action. The bay displays excellent examples of wave-cut notches, wave-cut platforms, stacks, stumps and caves, and as such it could possibly be used as an outdoor classroom.

Tour de Rozel
The beaches at Tour de Rozel are a good place to examine a range of sedimentary features associated with the Rozel Conglomerate. The majority of the exposure is coarse conglomerate (some of the clasts are over 50 cm in diameter) with well-rounded, poorly sorted clasts of a variety of lithologies. Bedding within the conglomerates is visible in places and the beds can be seen to have strongly erosive bases. Clast imbrication is also a feature of some of the units, indicating a southerly direction for the flow of the rivers that deposited these sediments.

There are also some sections in unconsolidated deposits exposed on the variably eroded 5e marine rocky platform, spreading out from the base of the cliffs. These appear to be head deposits, which are progressively sandier (loess) in the higher parts of the cliff.

The tall promontory of White Rock has well-developed notches cut into the bedrock that represent the 3 m and 8 m raised beaches.

St Lawrence's Church
This site is the parish church of St Lawrence, which is a great place to compare different types of building stones. The church was founded before 1198 but has been significantly remodelled several times during the intervening years. Various types of Jersey granite as well as rocks from

the *Jersey Volcanic Group* were used in its construction. The granites are seen in all stages of weathering, reflecting the ages of particular parts of the building. Imported *Chausey granite* is also used within the structural window surrounds, highlighting the ties between France and Britain during the Late Medieval Period. Inside the church is a Roman pillar of unknown origin that is both historically and geologically interesting,

St Martin's Church
The Anglican Parish Church of St Martin is first mentioned in a charter from 1042, but the building has a long and complex history of redevelopment, much of which is evident in its building stones and architectural styles. In addition to Jersey granites, dark red and green local rhyolite rocks can be found, especially in the porch. *Chausey granite* can be found in the eastern elevation windows. Blocks of Rozel Conglomerate were also used in the walls of the church, which is unusual, as the conglomerate is susceptible to erosion along the fracturing in its matrix. A wall that encloses the graveyard on the eastern side of the site is constructed of *Mont Mado granite*.

La Pallotterie
To the north of St Martin's Church is a lane called Rue de la Pallotterie. There are a number of buildings here that incorporate stones from Les Écréhous reefs to the north. This foliated granite is only rarely seen in buildings and its use is mainly restricted to this part of the Island. There is no natural exposure of the Écréhous stone on the Island and so this is a good place examine this rock. These buildings are private property and so permission must be sought to visit these properties.

St Catherine's Breakwater, and quarry
This site comprises the building stones of St Catherine's Breakwater, the low cliffs in the bay to the north and the quarries to the west. The extensive quarries to the west of the breakwater expose the *Rozel Conglomerate Formation*, which supplied material for the construction of the breakwater in the mid-19th century. Huge blocks of the conglomerate can be examined in the lower levels of the breakwater and on the beach to the north. The breakwater is also of interest because of the building stones that dress its upper sections. These provide a great opportunity to examine the various granitic textures found in Jersey and in the imported Cornish granite used as copings.

The central and northern part of the bay south of St Catherine's Breakwater exposes easily accessible outcrops of typical examples of the *Rozel Conglomerate Formation*, with large clasts up to boulder size set in a finer matrix. This location additionally displays some of the less common finer-grained units within the formation. The sediments of the *Rozel Conglomerate Formation* are thought to have been deposited in alluvial fans towards the end of the Cadomian Orogeny, and the imbrication of some of the flatter pebbles has suggested a source area to the north of Jersey.

4.2 SPECIAL LANDSCAPE AREAS (SLAs)

4.2.1 The intertidal reefs off the SE coast, proposed Special Landscape Area

Along the coastline and offshore of the south-east corner of Jersey is an area that is presently identified for conservation under the Ramsar Convention. Ramsar sites are identified to ensure the conservation of wetlands and their associated biodiversity. The area of intertidal reefs included in this Ramsar site is also important for its scenic qualities, historic buildings and important prehistoric sites. The geology exposed in the reefs is also important, as it provides an opportunity to examine a range of igneous rocks and Quaternary sediments. The existing Geological SSI of La Motte, Le Nez and Le Croc and the newly proposed SSIs of La Rocque and Le Dicq to the Lido (Havre des Pas) are included in this area. It is suggested that the boundary for this Special Landscape Area should follow the existing Ramsar site boundary (Figure 13).

The small tidal Island known as Green Island (La Motte) is one of only a small number of Islands that supports a sediment cap or beach deposits, loess and blown sand which contain archaeology. Green Island is the topographically highest part of an extensive area of reefs which extends discontinuously to the nearby rocky promontories of Le Nez and Le Croc. The bedrock is a lithologically variable part of the *South-east igneous complex*. Each of the three main outcrops within the site displays a distinct range of igneous textures, and collectively they present a revealing window into a dynamically evolving magma chamber. The site also includes good examples of the Jersey Main Dyke Swarm, and both La Motte and Le Nez provide excellent viewpoints over the largest intertidal rock platform (or reef) on the Jersey coast.

The intertidal zone around La Rocque Harbour, at the south-eastern extremity of mainland Jersey, has probably the best exposures of La Rocque granite of the *South-east igneous complex*; this granite is also the most extensive and youngest major component of the *South-east igneous complex*. This site also includes some of the best examples in Jersey of features found in fluid-rich magmas (coarse pegmatitic granite and miarolytic cavities).

The intertidal zone between The Dicq in the east and Havre des Pas Pier in the west exposes bedrock that is a lithologically variable part of the *South-east igneous complex*. The key geological features are contained in three separate outcrops within the intertidal zone. A large outcrop at The Dicq contains the best exposures of Dicq granite in any of the Jersey geodiversity sites. Low-lying exposures beside The Lido include a contact between Dicq granite and another granite body in the *South-east igneous complex*, possibly Longueville granite. Another large outcrop beneath Havre des Pas Pier presents spectacular examples of two types of magma interaction (magmatic brecciation and magma mingling) in multiple generations of diorite and granite; the resulting textures are clear evidence of a dynamic magma environment. Basalt dykes of the Jersey Main Dyke Swarm cut the outcrops at The Dicq and The Lido.

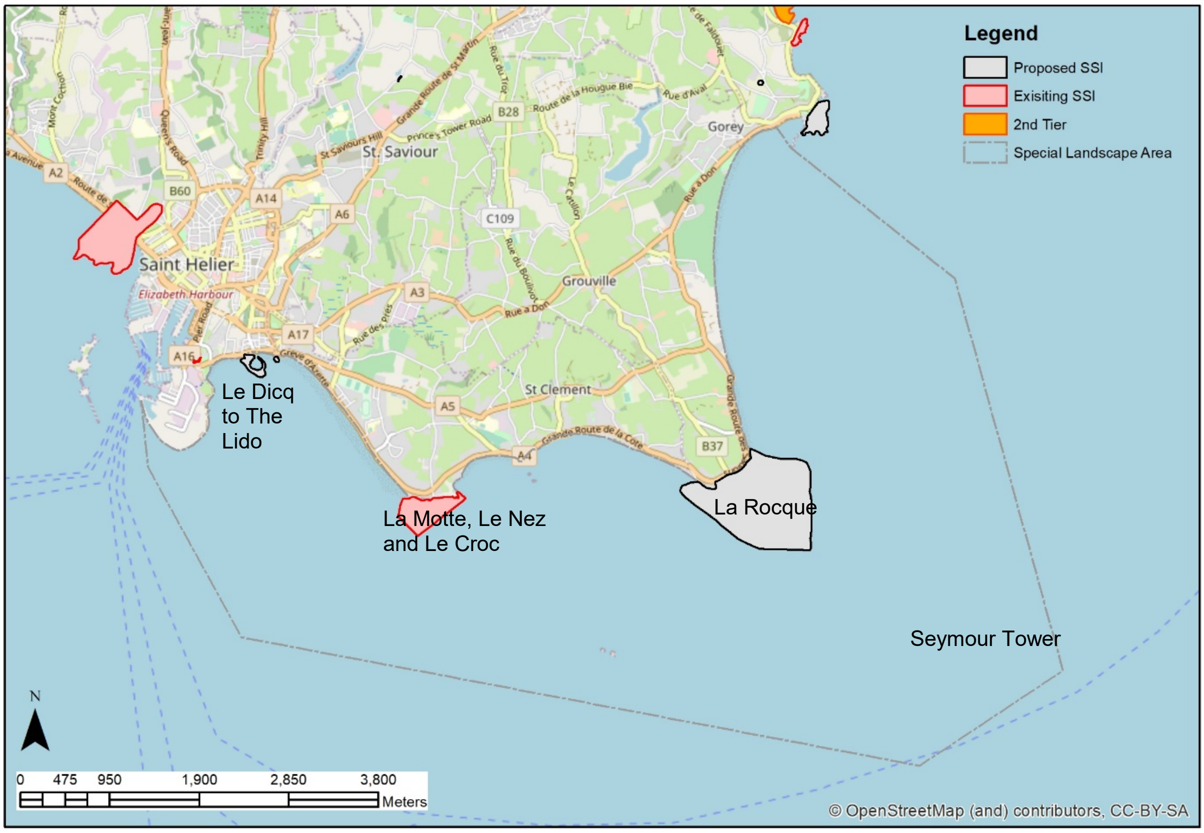


Figure 13 **Proposed Special Landscape Area for the intertidal reefs off the south-east coast.**

4.2.2 The Reefs, proposed Special Landscape Areas

The Bailiwick of Jersey includes a number of offshore reefs (Figure 14) and their extent is significant: together, they form an area four times larger than Jersey.

- Les Minquiers comprises a group of islands and rocks about 15 km south of Jersey. Although most of the rocks are submerged at high tide, at low tide they comprise an area larger than Jersey. The largest island, Maîtresse, is about 50 by 20 m and hosts about 10 cottages.
- Les Écréhous is a group of Islands and rocks 10 km north-east of Jersey. All but three of the Islands are submerged at high tide. The largest island is Maitre Ile and is about 300 m long; it has a few buildings. Another island, La Marmotiére, hosts an official custom house building.
- Les Dirouilles is an area of reefs to the north-east of Jersey.
- Paternosters (Les Pierre de Lecq) and a group of uninhabited reefs are located about 6 km north of Grève de Lecq, Jersey.

All of the reefs are protected under the Ramsar Convention as wetlands of international importance, and they are part of Jersey's Coastal National Park. However, they are also important as aesthetic landscapes, and they expose geology that is important for understanding the Cadomian Orogeny. They are also important landscapes for preserving prehistoric sites and artefacts.

The best understood group of islands in terms of their geology are Les Minquiers, where extensive geological mapping was carried out and published by Chambers *et al*. (2016), who described the following key rock units: quartz diorites exposed to the north, west and south of the main reefs; granodiorites forming the central parts of the reef; and a layered pegmatite/microgranite complex at Les Maisons. Chambers *et al.* suggested that Les Minquiers forms part of the Armorican Massif, which includes western Normandy, Brittany and the Channel Islands and underwent deformation and metamorphism during the Cadomian (syntectonic) and later Variscan orogenies.

A recent survey of Les Dirouilles by Chambers describes the reefs as a mainly subtidal complex of deep channels and around forty rocks. The rocks are predominantly foliated, medium-grained biotite granodiorite, rich in feldspars, quartz, biotite and muscovite. A dolerite intrusion and a pegmatite intrusion were also noted. Chambers *et al*. agree with earlier researchers (Noury, 1886) that the rock is very similar to that of Les Écréhous and Paternosters (Chambers, undated).

Pre-Holocene sediments are present in pockets in the bedrock surface in many places across the low-tide platform around Jersey. These include fine-grained, cold-climate silts with Middle Palaeolithic archaeology close to the modern cliff at Petit Portelet and similar types of sediments across the Violet Bank. On the Violet Bank, these sediments have produced similar sorts of artefacts as well as the occasional mammoth tooth. Other types of sediment are also preserved in these gullies; for example, at Petit Portelet, a gully lower down the foreshore contained remnants of raised beach materials with a characteristically distinct archaeological assemblage. Holocene sediments are preserved on some of these reefs. For example, peats are present on the Écréhous , while fine-grained organic silts are present on the parts of Les Minquiers that have been shown to contain prehistoric artefacts.

The history of Jersey through the Quaternary (as has been noted previously) is one of fluctuating sea levels. The result of this is that the present state of the island of Jersey is an anomalous state: for perhaps 90% of Quaternary time, Jersey would have been an upstanding element of a lowland landscape across the Normanno-Breton Gulf. This landscape of valleys, coasts, marshland and gullies is one that formed part of a contiguous domain through which humans and animals would have roamed during the cooler, low sea-level events of the Quaternary.

While this landscape is little studied, it is part of a broader western La Manche topography in which a wide range of rock types exist. To the south of Jersey, the geology is dominated by schists, shales, mudstones and sandstones of Neoproterozoic, Cambrian and Ordovician/Silurian ages. Similar deposits are found to the north of Jersey in the areas immediately surrounding the metamorphic and major intrusive rocks that form the Islands of Sark, Guernsey and Alderney. Palaeo-river channels and previous shorelines have cut through geological units, sculpting a gently undulating seafloor over the weaker rock types such as Mesozoic sediments (clays, chalk, siltstones and sandstones), while more rugged seafloor is marked by the regions of metasedimentary units. These topographies are significant because they were occupied by hominids, and the distribution of valley forms would certainly have influenced movement by these peoples. Furthermore, in a landscape largely devoid of commonly used raw materials for tool making (flint), outcrops of chalk on the seabed are likely to have played an important role in human behaviour when accessible.

Mapping these landscapes at a suitable resolution to investigate human behaviour is a priority for future investigation. The potential of these landscapes has been illustrated by the well-preserved sediments recovered during the site investigation for the laying of a cable from France to Jersey. Here, both Holocene and Pleistocene sediments were recovered from the submerged palaeovalley following the outcrop of Eocene limestones to the north and east of Jersey. These include fluvial sediments as well as palaeoenvironmentally important peat sequences containing ostracods, molluscs and small mammals.

The boundaries provided in Figure 13 are based on the best information available to date, and more detailed mapping should be undertaken to refine these boundaries in the future. These boundaries should be revised as further research is carried out.

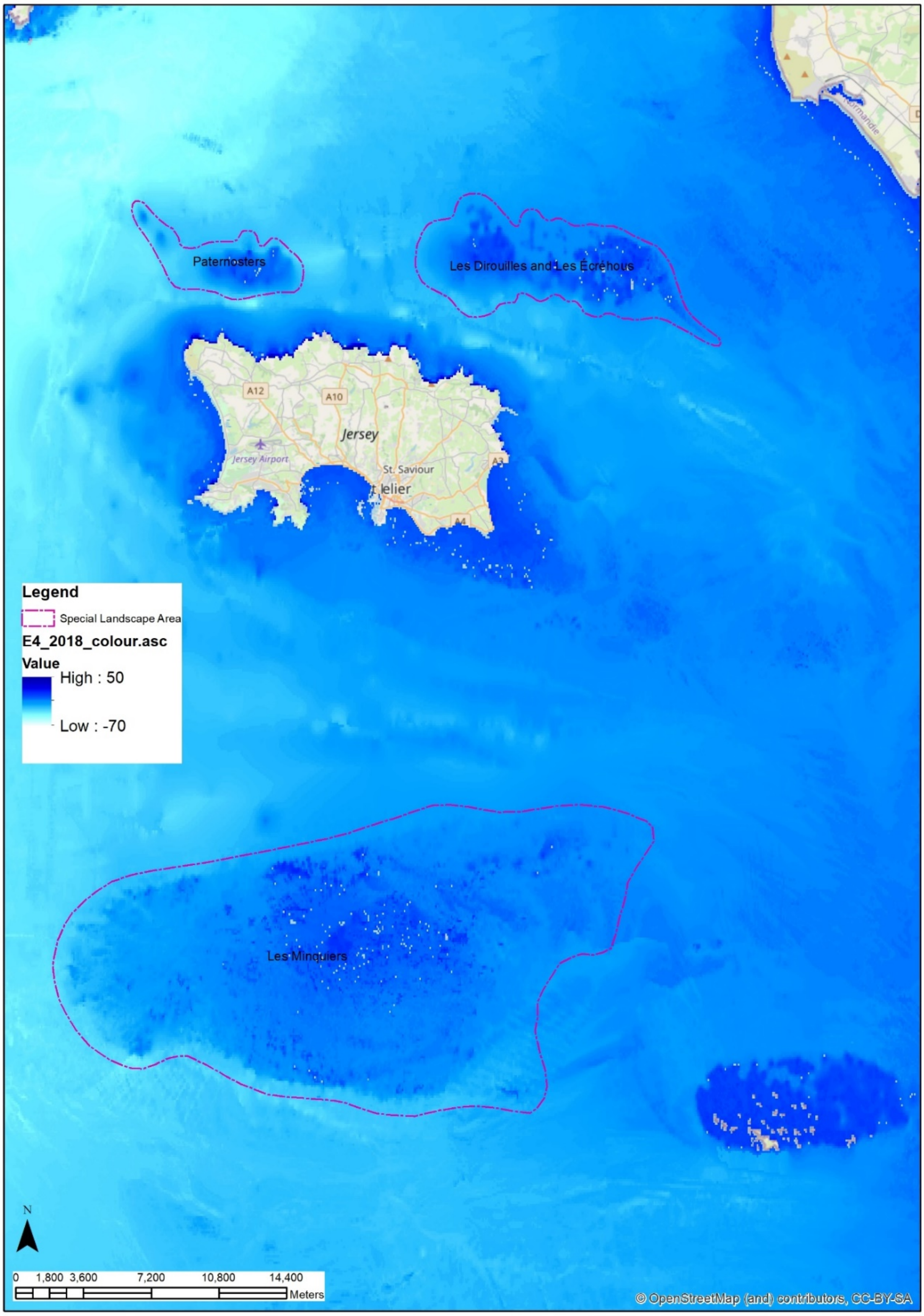


Figure 14 **Suggested boundaries for the Jersey Reefs SLA.**

(EMODnet Bathymetry Consortium (2018): EMODnet Digital Bathymetry (DTM). http://doi.org/10.12770/18ff0d48-b203-4a65-94a9-5fd8b0ec35f6)

4.2.3 St Ouen’s Bay, proposed Special Landscape Area

Backing St Ouen’s Bay is an abandoned cliff line that has been dated to at least the last warm stage. It is partly buried by recent blown sand deposits; however, the deposits of the bay reflect deposition over much of the Holocene. The periodic exposures of organic deposits on the foreshore have led to the characterisation of a St Ouen’s Bay peat bed. Revealed at very low tides, ‘ripple-topped’ peat beds are exposed south of Le Port. The peat contains stumps of birch and alder and dates from between 7 and 5 ka BP; it overlies older head deposits of probable Pleistocene and early Holocene age. Exposures at sand and gravel quarries in St Ouen’s Bay give important clues to the environmental history of the bay through the Holocene (the last 10 ka BP). There is evidence of fluvial erosion and transport across the bay early in the Holocene, followed by windblown remobilisation and the deposition of sand. Clay and peat layers are present in many locations and appear to occupy topographic lows between the fingers of head deposits spreading out from the valleys entering the bay. These head fans created a series of embayments in the earlier Holocene within which clay silts and peats accumulated. The distribution of the Neolithic monuments and areas of occupation around the Simon Sand Quarry and Les Blanches Banques dunes (The Ossuary, The Little Menhir, The Broken Menhir) and Les Mielles (Les Trois Rocques, The White Menhir) probably reflect the utilisation of the drier head ridges rather than the areas of wetter ground between them. At the Simon Sand Quarry, a prehistoric buried soil contains well-preserved evidence of Mesolithic and Early Neolithic activity, including actual settlements (McFadyen, In Prep). These more stable zones appear to be linked with common archaeological artefacts, implying quite extensive use of the area by humans at this time. This later prehistoric landscape is buried now by blown sand deposits that are most extensive in the south of the bay, where they extend 2 km inland, enveloping higher parts of the prehistoric record (The Great Menhir, La Tete de Quennevais). The archaeology of this landscape was usefully brought together in the Patton and Finlayson (2001) report.

This important archaeological and palaeoenvironmental record is threatened by economic activity, by wind and foot erosion within the dunes of Les Blanches Banques and through wave action on the foreshore. Where wave action exposes archaeological material, this material is further at risk from undocumented collection. The localities known to preserve evidence for human activity on the foreshore (Le Ousiere, La Saline, Les Laveurs) document the presence of internationally important settlement records, including some of the earliest Neolithic ceramics in Jersey and a rare, imported jadeite axe. It is important that these locations are not viewed just as sites in isolation, but rather as localities where exposures have revealed, and individuals have reported a record of, an extensive and important palaeolandscape underlying the coastal plain of St Ouen’s in front of the ancient inland cliff line.

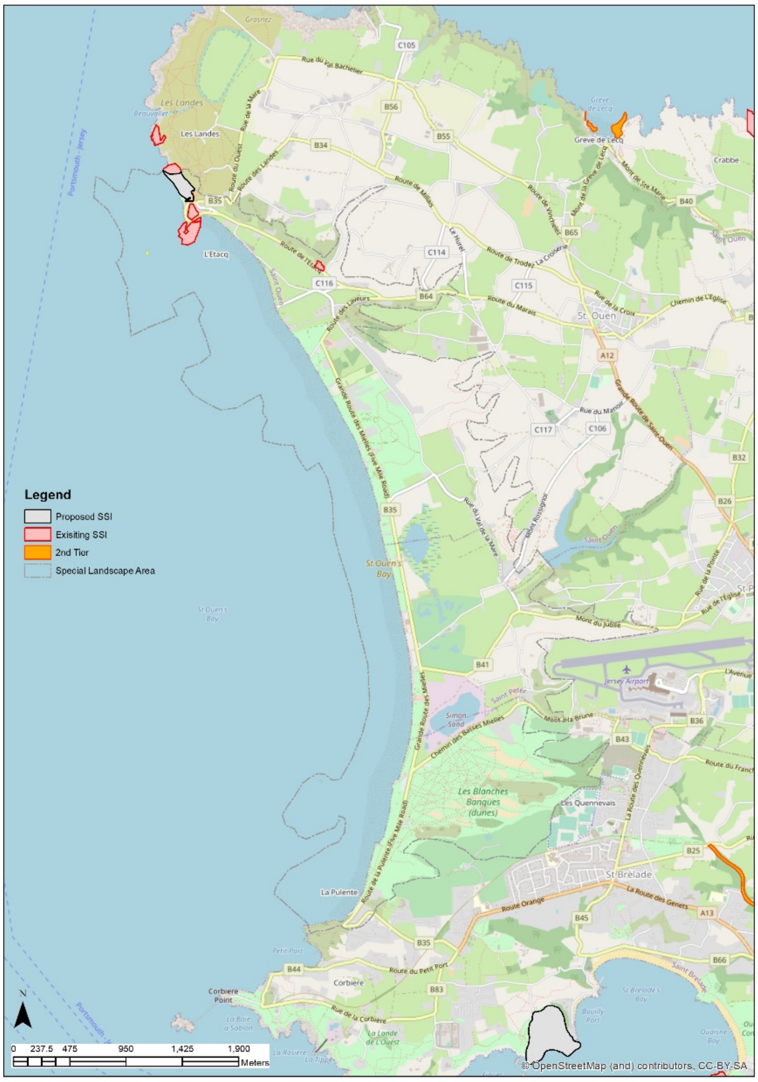


Figure 15 **St Ouen's Bay Special Landscape Area.**

4.3 ARCHAEOLOGICAL/PREHISTORIC-SCALE SITES

This section discusses the potential of Quaternary sediments for archaeological and palaeoenvironmental records.

Jersey has an extensive and generally well-mapped range of Quaternary deposits spanning more than 300,000 years. These deposits include blown sand, peat, alluvium, fine-grained head deposits such as loess, coarser head gravels, raised beach deposits and locally, within the Belle Hougue caves, speleothems (Bates, 2003; Jones *et al.*, 1987; Keen, 1982; Pope *et al.*, 2015). While many of these deposits are understood through past investigations of particularly well-researched locales such as Portelet or Belcroute, some of which are designated and well protected, the overall importance of these deposits is their spatial extent and depth. Compared to the British Isles, which overall have a more patchy and sparse coverage, the distribution of these scientifically important sediments is close to continuous across Jersey, with only some areas of slopes and headlands devoid of meaningful depths of sediments.

The coverage and depth of deposits, for example, more than 5 m of loessic head on the plateau and peaty alluvium up to 6 m deep in **St Ouen's Bay**, St Helier and Grouville Marsh, mean that the best-preserved archaeological and scientific records lie wholly hidden and undetected (Keen, 1978). Approaches to heritage and scientific protection have understandably centred on designated assets, i.e., SSIs, and this has been valuable. There has been a focus on monuments, sites and 'flint' scatters without fully recognising that these 'sites' are part of a continuum of human activity at a landscape scale (Bates and Wenban-Smith, 2011), i.e., at an Island-wide scale (part of the Island's landscape), and this can only be understood and appreciated by adopting a geoarchaeological approach to the Island.

Overall, geoarchaeological expertise has been poorly applied to the task of connecting the geological, palaeoenvironmental and archaeological records. This in part reflects the relative dearth of scientific investigation into the Quaternary record of Jersey over the last 30 years, while the development of the subject in the UK has grown exponentially (Bates, 2018). This also reflects the focus of attention towards the coastal sector (where sequences are exposed), with only minimal attention being paid to the buried Quaternary resources away from the cliffs. The result is that the wider record of the deeply buried palaeolandscape has been under-researched, under-protected and left open to destruction through development. It is impossible to quantify what has been lost, but we can document examples of the internationally important archaeology that forms part of this Quaternary sedimentary record and gives an indication of the quality of the record that lies preserved within these sedimentary blocks:

- Les Varines, an exceptional Upper Palaeolithic site with structured hearths and Ice Age art, is preserved at between 0.5 and 3 m depth in deposits mapped as head (Pope *et al.*, 2015; Conneller *et al.*, 2016) at the top of a buried cliff line. Furthermore, older raised beach deposits lie at depth at the foot of the cliff.
- The Gasworks Dolmen lay at a depth of 4.5 m in deposits mapped as alluvium (Kinnes, 1988).
- The St Ouen's continuous Neolithic and Bronze Age palaeolandscape, containing buried megalithic structures, rare Neolithic settlements, peat outcrops with trees and human and animal footprints, is mapped as blown sand (Patton and Finlayson, 2001; McFadyen *et al.*, In Press). This may also be the case on the eastern part of the Island around Grouville.
- The two Ville-és-Nouaux Dolmens lay under deposits mapped as blown sand.
- While St Peter's Valley is often flagged as a rich source of palaeoenvironmental information, this is simply because it was documented by Jones *et al.*, who felt that every major Jersey Valley has potential (Jones *et al.*, 1990).

Consequently, alongside SSIs, the Island needs to reconsider the nature of the mapped Quaternary deposits, and potentially the way in which they are mapped, with the scientific and archaeological potential of these deposits being considered during planning and development control. The first stage of this process is to consider the Island as a continuous three-dimensional body rather than as a series of isolated (yet correlated) two-dimensional records. Approaches from southern England to thinking about the three-dimensional resources that have been / are being developed in Kent and Essex may provide a template for Jersey to build on. In these cases, landscapes have been subdivided into zones of higher or lower archaeological potential based on the consideration of the sub-surface geology and the associated/assumed archaeology. These zones have a variety of scales and may differ in shape/size by period. For example, Final Palaeolithic / Mesolithic zones may overlap or diverge from zones for Middle Palaeolithic archaeology. While it is premature to designate such zones in Jersey without an adequate appraisal of both their archaeological and geological records, St Ouen's Bay may be considered as an example. At the largest scale, a single high-potential zone for Holocene archaeology might be applied from the bay area inland to the rising bedrock cliffs. (There are, however, arguments for sub-dividing the area into a series of zones of differing potential.) By contrast, a zone defining Middle Palaeolithic (if present) archaeology might include a high-potential zone close to the cliff line and a low-potential zone away from the cliff line. Any impact on these deposits through development or erosion needs to be considered within a geoarchaeological framework by a qualified geoarchaeologist in terms of what is required for mitigation and assessment. For coastal exposures, some provision needs to be put in place to provide resources for expertise to be rapidly and responsively deployed in response to the storm damage / removal of mobile beach sediments to make appropriate records and rescue artefacts and structures. Some of these deposits, such as coastal peats, are rich in artefacts and could do with wider protection from the casual collection of artefacts (e.g., at La Saline). In the absence of heritage legislation protecting artefacts and structures eroding out of Quaternary sediments, developing the capacity for well-funded and expert responses to threats due to coastal erosion should be considered a priority. Seeing this record of the human story as one of the most important parts of the geodiversity of Jersey is key to properly protecting, understanding and explaining it. Threats to these sediment blocks through development can be mitigated through developer-funded archaeology that is implemented and enforced through planning. Responses to threats due to coastal erosion could be covered through climate emergency funding. Impacts due to agriculture, tree planting, etc., which fall outside of planning permissions, provide a scope for community-based work. Any other impacts, such as individual or group artefact collection and metal detecting, should be discouraged, preferably through legislation.

As set out here, the biggest challenge facing the conservation of Quaternary geology and interpreting it for the public is recognising its spatial extent and high potential to deliver important scientific and archaeological finds. Such discoveries can attract real public interest in terms of their media, tourism, educational and reputational value for Jersey on the international stage. The priority should be, building on Bishop and Bisson's (1989) map (Figure 19), to map and designate the full extent of these buried Quaternary deposits. In the future, the best localities, allowing for accessible and well-interpreted viewing, could be identified and proposed as managed SSIs within these areas of Quaternary potential. As they become better understood through research and investigation as part of the planning process, the character, extent and relevant importance of each area will become better understood and refined.

- To this end, we would like to recommend a mapping project to further define and characterise Jersey's Prehistoric Landscape Zones (PLZs) for inclusion in the Historic Environmental Record (HER).
- Isolated finds and assemblages should be reassessed in light of this characterisation exercise.
- The accessibility and interpretation of these landscape-scale heritage and scientific assets should be developed for enhancement and engagement in the future.

5 Discussion of Conservation and Uses of Geodiversity Sites

5.1 INTRODUCTION

The purpose of geoconservation is to ensure that societal benefits from geodiversity and geoheritage are realised. These benefits can be manifested in a range of social, educational, environmental and economic contexts, and they are increasingly being recognised as important factors in sustainable development, the mitigation of climatic change and the reversal of biodiversity loss.

Geoconservation is a response to the vulnerability of many geodiversity and geoheritage sites. Although rocks and landscapes may appear to be solid and fixed, they are irreplaceable and are often vulnerable to a number of activities and land use practices. The removal of rocks at a number of scales, ranging from quarrying to small-scale collection, may pose a significant threat, and unmanaged vegetation growth, weathering and the disturbance of sites may obscure rocks and landscapes. Geoconservation is therefore necessary to ensure that the benefits of geodiversity can be felt today and enjoyed by future generations.

The following section provides an overview of the political and legal contexts for the designation and protection of geodiversity in the UK, the nature of geoconservation practices and case studies. Geoconservation is then considered with respect to Jersey.

5.2 GEOCONSERVATION IN THE UK

In the UK, the main means of geoconservation is through the designation of special areas. In many cases, sites that have a formal designation represent the best examples of a particular aspect of Earth science (e.g., minerals, fossils or past climate conditions) and are managed in order to conserve their special features. In other cases, the protection of geodiversity may arise as a by-product of landscape designations that may not be primarily due to the geodiversity of an area but nevertheless provide a level of protection for geodiversity sites.

Some designations offer a much higher level of protection than others and in some cases an area can receive multiple designations. A brief summary of the relevant designations in the UK has been provided below.

5.2.1 International designations

5.2.1.1 UNESCO GLOBAL GEOPARKS

UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic approach involving protection, education and sustainable development. A UNESCO Global Geopark uses its geological heritage, in connection with all other aspects of the area's natural and cultural heritage, to enhance the awareness and understanding of key issues facing society, such as using Earth's resources sustainably, mitigating the effects of climate change and reducing natural disaster-related risks.

To achieve UNESCO Global Geoparks status, an area must have internationally important geological heritage. This is independently verified at the application stage by the International Union of Geological Science (IUGS).

UNESCO Global Geoparks are not statutory designations, meaning that they are not protected by specific legislation and they do not necessarily place restrictions on land use and development. However, each UNESCO Global Geopark works with pre-existing designations and must respect local and national laws relating to the protection of geological heritage. The defining geological heritage sites within a UNESCO Global Geopark must be legally protected in advance of any application.

By raising awareness of the importance of an area's geological heritage in history and society today, UNESCO Global Geoparks give local people a sense of pride in their region and strengthen their identification with the area, helping to further protect the area's geological heritage.

5.2.1.2 WORLD HERITAGE SITES

A World Heritage Site is a place that is listed by UNESCO as having natural or cultural heritage of Outstanding Universal Value. Such sites are considered irreplaceable treasures.

To be included on the World Heritage List, sites must, through research, demonstrate that they have Outstanding Universal Value and integrity, which is basically a measure of their quality. They must also demonstrate that they meet at least one out of ten selection criteria. These relate to both natural and cultural heritage; however, just two criteria (vii and viii) relate to geology, landscapes and Earth science.

Criterion vii: To contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.

Criterion viii: To be outstanding examples representing major stages of Earth's history, including the record of life, significant on-going geological processes in the development of landforms or significant geomorphic or physiographic features.

World Heritage Sites are not statutory designations and do not necessarily place restrictions on land use and development; however, local or central authorities may choose to put restrictions in place on land use development within and in close proximity to a World Heritage Site.

5.2.1.3 RAMSAR SITES

Ramsar sites are wetlands listed under the Ramsar Convention, which protects wetlands of international importance. It requires signatories to formulate and implement a plan for the conservation and wise use of wetlands and their resources. As a matter of policy, the UK government has chosen to apply the procedures under the Habitats Regulations to Ramsar sites. Although not directly related to geoconservation, Ramsar sites are dependent on their underlying geodiversity for their development, and therefore protection is offered indirectly.

5.2.2 Regional or 'European' designations

5.2.2.1 NATURA 2000 SITES

Natura 2000 Sites form a network of sites that aims to maintain rare or endangered species and habitats at a favourable conservation status throughout Europe; they include Special Areas of Conservation (SACs) and Special Protected Areas (SPAs). While there is no provision for geological sites to be designated Natura 2000 sites, many of the habitats and the resulting species are a direct result of the underlying geology. The protection of important plants and animals can provide indirect protection for geological features.

5.2.2.2 SPECIAL AREAS OF CONSERVATION

Special Areas of Conservation (SACs) are areas that have been protected under the EU Habitats Directive and Habitats Regulations and are meant to safeguard habitats and species that are rare or threatened in a European context. Designation as an SAC restricts any activity that could cause the deterioration of habitat types and the habitats of a species, as well as the disturbance of a species for which an area is designated. Consent must be sought and will not be granted if an activity is deemed likely to have an adverse effect on the integrity of the site.

5.2.2.3 SPECIAL PROTECTION AREAS

Special Protection Areas (SPAs) are areas that have been protected under the EU Birds Directive (Directive on the Conservation of Wild Birds), and they are protected because they are important areas for breeding, overwintering and migrating birds. Classification as an SPA restricts any activity that could have a negative impact on the site. Consent must be sought and will not be granted if an activity is deemed to have an adverse effect on the integrity of the site.

5.2.3 National designations

5.2.3.1 SITES/AREAS OF SPECIAL SCIENTIFIC INTEREST (SSSIs AND ASSIs)

Sites of Special Scientific Interest (SSSIs) in England, Scotland and Wales and Areas of Special Scientific Interest (ASSIs) in Northern Ireland are meant to protect the most important areas for plants, animals and geology. They are the foundation of site-based geoconservation, and many other conservation designations are based upon these sites/areas. They are areas of land that have been identified by scientific survey as important areas that should be conserved.

Although they are very similar, the legal arrangements for SSSIs and ASSIs differ between the four regions of the UK. The decision to designate an SSSI or ASSI is made by the relevant statutory nature conservation body: Natural England, Natural Resources Wales, the Northern Ireland Environment Agency or Scottish Natural Heritage. The current legal framework for SSSIs in England and Wales is the Wildlife and Countryside Act 1981, which was amended in 1985 and again in 2000 (by the Countryside and Rights of Way Act 2000). In Scotland, the current legal framework is the Nature Conservation (Scotland) Act 2004, and in Northern Ireland, it consists of the Nature Conservation and Amenity Lands (Northern Ireland) Order 1985 and the Environment (Northern Ireland) Order 2002.

When designating a site as an SSSI or ASSI, the relevant nature conservation body must formally notify the interested party. This includes a description of the land and its natural features, a boundary map and a list of the acts and omissions that are regulated through the issue of consent.

5.2.3.2 NATIONAL NATURE RESERVES (NNRs)

National Nature Reserves (NNRs) were established to protect some of the UK's most important habitats, species and geology and to provide 'outdoor laboratories' for research. The primary aim of managing these sites is to conserve their features through the development of experience and techniques in managing land for conservation. However, they have a secondary aim: providing opportunities for the public to experience these natural habitats and landscapes.

The majority of National Nature Reserves are owned and managed by the government and approved partners; however, where this is not the case, the government will work with and support landowners to conserve wildlife, habitats and geology.

5.2.3.3 AREAS OF OUTSTANDING NATURAL BEAUTY (AONBs)

Areas of Outstanding Natural Beauty (AONBs) are used to formally recognise distinct landscapes of high scenic value. By designating AONBs, the government recognises that the landscape deserves extra care so that its special qualities can be shared with future generations.

AONBs are a statutory designation that permits the government to make provisions for the conservation and enhancement of the area's natural beauty and increase the awareness and public enjoyment of the area. This is usually achieved through support for voluntary and non-governmental AONB Partnerships.

AONBs help protect outstanding landscapes, providing space for healthy outdoor living, recreation and work. Access for recreation and tourism is desirable, but no landowner has to allow members of the public onto their land without permission.

AONB status does not limit a landowner's options to expand their operations or to obtain planning consent; however, it is important that they take the outstanding landscape into account when developing proposals. Designation as an AONB allows for the (non-compulsory) management of the landscape, in order to maintain its quality and special features and to enhance public access and enjoyment. This is accomplished through AONB Management Plans.

5.2.3.4 NATIONAL PARKS

The International Union for the Conservation of Nature (IUCN) has identified National Parks as a category of Protected Landscape; they are defined as 'large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.'

According to the IUCN classification, there are no 'true' National Parks in the UK, as this would require large areas to be set aside for protection. However, the National Parks in the UK are areas of outstanding landscapes where habitation and commercial activities are restricted.

National Parks in the UK are a devolved matter, with each region having its own policies and arrangements. There are 15 National Parks in total, and they all have two main purposes: to conserve and enhance the natural and cultural heritage of an area, and to promote the understanding and enjoyment of the special qualities of the National Park by the public. There are currently no National Parks in Northern Ireland.

5.2.4 Local designations

5.2.4.1 RIGS

Regionally Important Geological and Geomorphological Sites (RIGS) are locally designated sites of local, national and regional importance due to their geodiversity.

RIGS do not have the statutory protection that sites such as SSSIs and ASSIs enjoy; instead, they are conserved and protected from development as material considerations through the planning system. The presence of RIGS varies across the UK.

5.2.4.2 LOCAL NATURE RESERVES

Local Nature Reserves are a statutory designation that includes places with wildlife or geological features that are of special interest locally. They are usually selected and designated by local authorities.

An area to be designated must be at least of local importance in terms of its natural heritage and wholly within the area of the local authority planning to designate it a reserve. It must be owned or leased by the local authority, or the owner(s) must formally agree to the designation.

5.2.4.3 SITES OF LOCAL NATURE CONSERVATION IMPORTANCE

Sites of Local Nature Conservation Importance (SLNCIs) are sites that support habitats, species or Earth science features. As well as making a contribution to the local natural heritage, they contribute to national and European biodiversity and geodiversity. The location of such a site is identified through the relevant area plan.

5.3 GEOCONSERVATION WITHIN THE UK PLANNING SYSTEM

The planning system is key to geoconservation across the UK. Geoconservation is accomplished using the planning system in three ways: through the statutory framework for designated sites, national planning policies and local development plans.

5.3.1 Statutory framework

All of the regions of the UK have areas that are important due to their geodiversity, and many of these have merited statutory designation and are protected under international (including European), national or local legislation and convention. This statutory framework is key in developing policy to protect geodiversity, and it is a requirement that statutory obligations are met. The applicable international, national and local legislation and conventions have already been discussed.

5.3.2 National planning policy

All of the regions in the UK have national planning policies in place. All of these include some form of requirement to protect geodiversity. These policies are summarised below.

5.3.3 National Planning Policy Framework (England)

The National Planning Policy Framework sets out the government's planning policies for England and how they should be applied. It provides a framework within which locally prepared plans for housing and other development can be produced. Geodiversity is included in a number of sections:

1. Conserving and enhancing the natural environment

Planning policies and decisions should contribute to and enhance the natural and local environment by protecting and enhancing valued landscapes, sites of biodiversity or geological value and soils (in a manner commensurate with their statutory status or identified quality in the development plan).

2. Habitats and biodiversity

To protect and enhance biodiversity and geodiversity, plans should: Identify, map and safeguard components of local wildlife-rich habitats and wider ecological networks; promote the conservation, restoration and enhancement of priority habitats, ecological networks and the protection and recovery of priority species; and identify and pursue opportunities for securing measurable net gains for biodiversity.

5.3.3.1 PLANNING POLICY WALES

Planning Policy Wales (PPW) sets out the land use planning policies of the Welsh government. The primary objective is to ensure that the planning system contributes to the delivery of sustainable development and improves the social, economic, environmental and cultural well-being of Wales. Geodiversity is recognised in a number of ways, primarily through long-term protection and collaboration.

1. Long-term protection

Development plan strategies, policies and development proposals should be formulated to look to the long-term protection and enhancement of the special characteristics and intrinsic qualities of places. This means both protecting and enhancing landscapes, habitats, biodiversity, geodiversity and the historic environment in their own right as well as other components of the natural world, such as water resources or air quality.

2. Collaboration

Collaboration must occur in strategic planning for the protection and enhancement of landscapes, the historic environment, biodiversity, geodiversity, air quality and soundscapes. There will be issues which require cross-boundary collaboration and will be best addressed through joint work on development plans.

5.3.3.2 SCOTTISH PLANNING POLICY

The Scottish Planning Policy lays out national planning policies for the operation of the planning system and for the development and use of land. It directly relates to the preparation of development plans; the design of development, from the initial concept to delivery; and the determination of planning applications and appeals.

Geodiversity is directly applicable in the following areas in *Development Plans*:

1. International, national and locally designated areas and sites should be identified and afforded the appropriate level of protection in development plans. Reasons for local designation should be clearly explained and their function and continuing relevance considered when preparing plans.

2. Local nature conservation sites designated for their geodiversity should be selected for their value for scientific study and education, their historical significance and cultural and aesthetic value, and for their potential to promote public awareness and enjoyment.

5.3.3.3 STRATEGIC PLANNING POLICY STATEMENT (NORTHERN IRELAND)

The Strategic Planning Policy Statement (SPPS) for Northern Ireland lays out the regional planning policies for securing the orderly and consistent development of land in Northern Ireland under the two-tier planning system. The provisions of the SPPS must be taken into account in the preparation of Local Development Plans, and they are also relevant to all decisions on individual planning applications and appeals.

The SPPS is supported by a number of Planning Policy Statements (PPSs), one of which, PPS 2 – Natural Heritage, is particularly relevant for geodiversity. PPS 2 describes the planning policies for the conservation, protection and enhancement of natural heritage, which is defined as 'the diversity of our habitats, species, landscapes and earth science features'. There are a number of relevant sections in PPS 2:

1. Policy Objectives

The objectives of this Planning Policy Statement are:

- to seek to further the conservation, enhancement and restoration of the abundance, quality, diversity and distinctiveness of the region's natural heritage;
- to further sustainable development by ensuring that biological and geological diversity are conserved and enhanced as an integral part of social, economic and environmental development;
- to assist in meeting international (including European), national and local responsibilities and obligations in the protection and enhancement of the natural heritage; and
- to protect and enhance biodiversity, geodiversity and the environment.

2. Planning Permission

Planning permission will only be granted for a development proposal which is not likely to result in the unacceptable adverse impact on, or damage to known:

- features of earth science conservation importance;
- features of the landscape which are of major importance for wild flora and fauna; and
- other natural heritage features worthy of protection.

5.3.4 Locally prepared plans

In all of the regions of the UK, locally prepared plans are a key tool for geoconservation. These are crucial for carrying out the national planning policies and the statutory frameworks as well as taking into consideration local needs.

5.4 METHODS OF GEOCONSERVATION

Geoconservation can be approached in a multitude of ways, with a number of methods that could be used in any one area.

5.4.1 Research

Pure and applied geoscience research is a useful tool for geoconservation that can be used to better understand geodiversity and how it is connected to other aspects of the environment. This is essential for exploring past environmental change and discovering how we can mitigate and adapt to the future effects of climate change through sustainable land-use management.

5.4.2 Policy and legislation

It is essential to recognise geodiversity in international, national and local environmental and planning development policies and to demonstrate the role that geodiversity plays across all aspects of the natural and built environment. Increasingly, it is important to understand the role that geodiversity has to play in sustainable development, particularly for the delivery of the UN Sustainable Development Goals.

5.4.3 Information gathering

Gathering and maintaining data on geodiversity is a vital part of geoconservation. This includes not only site audits but also the interpretation of each site. Information gathering should also include underpinning data such as maps, specimens, photographs and other documents that support and augment geoconservation.

5.4.4 Conserving and managing sites

It is necessary to recognise the importance of geodiversity at international, national and local levels and to put appropriate site management in place, as well as management of the wider area and landscape if appropriate.

5.4.5 Education and outreach

Geodiversity should be interpreted for a wide range of audiences and communities, and it should be made relevant to where people live and work. The links between geodiversity and all other aspects of natural, built and intangible heritage should be communicated in innovative ways. Geodiversity education is a vital component of geoconservation, and the relevant interpretation of geodiversity and resources to widen the understanding of geodiversity should be part of both formal and informal learning.

5.4.6 Partnerships and collaboration

Geoconservation is not possible without involving a wide range of partners at all levels, including the development of policy, compiling education resources, carrying out site audits and managing geological sites.

5.5 GEOCONSERVATION CASE STUDIES IN THE UK

There are many organisations in the UK that have demonstrated good practice in the field of geoconservation, often using a wide range of methods, as discussed previously. The scale of these case studies varies wildly, from whole regions of the UK down to site-specific examples, but all demonstrate good practice.

5.6 SCOTTISH GEODIVERSITY CHARTER

Scotland was the first of the four devolved regions of the UK to produce a Geodiversity Charter that encourages the promotion and management of Scotland's geodiversity and the improved integration of geodiversity into policy and guidance, consistent with the economic, social, cultural and environmental needs of Scotland.

The Charter presents a vision for safeguarding Scotland's geodiversity for existing and future generations, something that can only be achieved by working in partnership. To date, more than 90 organisations, large and small, from across Scotland and beyond have signed up to support the Charter, and many of them have been used as case studies within the document.

The Scottish Geodiversity Charter was first published in 2012 and has been revised and updated for 2018 –2023. The good practice demonstrated in the Charter has paved the way for both the English and Northern Ireland Geodiversity Charters, both of which have now been published and aim to improve geoconservation at a national scale through effective partnerships and awareness raising.

5.6.1 North Pennines AONB / Geopark Geodiversity Audit and Action Plan

In 2004, the North Pennines AONB Partnership produced the first Geodiversity Audit and Action Plan for a protected landscape in the UK. The Audit is an account of all the features that contribute to the geodiversity of the North Pennines, from the oldest rocks to the most recent deposits. It summarises the geological evolution of the area and also the ways in which the area's rocks and minerals have been used over the centuries.

The Geodiversity Audit accompanies the Geodiversity Action Plan, which guides the conservation and interpretation of geological features in the North Pennines AONB and Geopark and also supports the development of sustainable geotourism in the area.

This comprehensive suite of documents was a first for the UK and acted as a leading example of how to manage and conserve a protected landscape in the UK through partnership and collaboration.

5.6.2 Giant's Causeway and Causeway Coast World Heritage Site management plan

It is UK government policy that all World Heritage Sites (WHSs) have management plans to fulfil their obligations under the World Heritage Convention. The first plan for the Giant's Causeway and Causeway Coast WHS was published in 2005 and covered the period up to and including 2012.

The second management plan was delivered to cover the period from 2013 to 2019, with the ultimate aim of the WHS being recognised as a global leader in the sustainable management of dynamic cultural sites, inspiring people to celebrate, value and enjoy a site that offers a world-class visitor experience.

The WHS Steering Group developed the management and action plan to guide the actions of the Steering Group as well as the external organisations that make decisions affecting the site. The main objectives of the plan were as follows:

1. Protect and conserve the Outstanding Universal Value of the World Heritage Site and its setting for present and future generations.
2. Support and demonstrate good WHS management.
3. Raise public awareness of the Giant's Causeway and its WHS/International status.
4. Provide a safe and enjoyable visitor experience that does not compromise the Outstanding Universal Value of the Site.
5. Engage local communities with the WHS and enable them to gain greater benefits from the WHS designation.

5.7 GEOCONSERVATION IN JERSEY

The section below provides a brief summary of the current geoconservation in Jersey.

5.7.1 Statutory designations

5.7.1.1 SITES OF SPECIAL INTEREST

Sites of Special Interest (SSIs) in Jersey are broadly similar to SSSIs and ASSIs in the UK. They are a conservation designation used to protect a site's special biological or geological features; 22 of these sites have been designated as SSIs because of features of geological interest.

When selecting an SSI, the site needs to meet the Ratcliffe Criteria, 10 intrinsic qualities worthy of protection. These qualities include the fragility of the site and its rarity, position, naturalness and intrinsic appeal.

SSIs can be in public or private ownership, and under the Planning and Building (Jersey) Law 2002, the Department of the Environment must keep a list of places or buildings of special zoological, botanical, ecological, geological, archaeological, architectural, artistic, historical, scientific or traditional interest.

5.7.1.2 NATIONAL PARK

The Jersey Coastal National Park (CNP) is the first designated National Park in the Channel Islands and was designated in 2011 following the adoption of the 2011 Island Plan, with parts of

Jersey's coast and countryside being recognised as areas of local, national and international importance. The level of protection that National Park status offers in Jersey is unclear.

A management plan for the CNP was compiled in 2015 (the duration of this plan is unclear) but there is little recognition of geodiversity and/or geoconservation within this plan except for one mention in the background section. There are a number of main themes identified, one of which is the natural environment, and neither the vision nor the associated action plan under this section includes geodiversity.

5.7.2 Island Plan

The Island Plan for Jersey is centred on three concepts: countryside protection; the wise use of resources; and urban regeneration, with the protection of the coast and countryside being a key aspect.

The Island Plan is the primary consideration in any planning-related decision-making and the law states that all development should be in accordance with the Island Plan unless there is sufficient justification for not following it. This makes the Island Plan a highly significant document.

The strategies and objectives of the Island Plan are translated into a framework of policies and proposals that will provide the basis for land-use planning decisions.

It should be noted that there is currently no provision for (or mention of) geodiversity within the current Island Plan, and any mention of the natural environment is in relation to biodiversity only.

Work is underway on the Island Plan 2021 to 2030, which will set out the plan for Jersey's growth over the next 10 years and will provide the key framework against which planning decisions are made. This document is crucial for ensuring the conservation and management of Jersey's geological heritage, and geodiversity should be considered alongside biodiversity.

5.7.3 Biodiversity Strategy

Jersey's Biodiversity Strategy was published in 2000, and it is one of the strategies that is taken into consideration by the Island Plan. The main aim of this strategy is to conserve and enhance the biological diversity in Jersey and to contribute to the conservation of global biodiversity when appropriate.

This thoroughly comprehensive document is an excellent example of a large-scale approach to conservation and of how that approach is then applied to produce more focused local biodiversity action plans to achieve the recovery of the most threatened species and habitats. There is little mention of the links between geodiversity and biodiversity and the impact that geological heritage has.

5.8 DISCUSSION

Geoconservation is taking place all across the UK and in other countries around the world through a variety of means, including legislative statutory frameworks for designations, planning policies and numerous initiatives, such as the development of geodiversity action plans and geodiversity charters.

There is no single approach taken to geoconservation; even the planning policy documents for the four devolved regions of the UK vary in their approach to and inclusion of geodiversity and the need to protect and conserve it.

In the case of planning policy, there is a bias towards biodiversity in all cases, with a significant amount of consideration given to the conservation of species and habitats and a lesser amount of consideration given to geodiversity. This is possibly due to a lack of understanding of the importance of geodiversity, something that is slowly changing.

Although there are arguably adequate provisions for geoconservation in the UK, the best results are seen where action plans have been put in place and delivered, either formally or informally. This takes a multi-faceted approach to geoconservation and includes a number of elements, such as research, policy and legislation, information gathering, conserving and managing sites, education and outreach, all delivered through partnerships and collaboration.

Jersey is slightly different from the UK and does not enjoy the same wealth of statutory designations that can provide geoconservation, either directly or indirectly. This can be seen as a good thing by landowners, as it minimises the number of restrictions on land use and development, but for geoconservation, this can be detrimental: potentially important geological sites may be at risk due to a lack of protection.

Jersey benefits from being a small geographical area with central control over planning and development, with the Island Plan being the primary consideration in any planning-related decision-making. Currently, there is no provision for geodiversity, and therefore for geoconservation, within the Plan; the current review of the Plan could be the ideal opportunity to address this.

The importance of biodiversity has long been recognised in Jersey and the Biodiversity Strategy is a testament to this. The same cannot be said for geodiversity, which seems to be completely lacking recognition despite the fact that the two are complementary. However, the development of the Biodiversity Strategy and associated Local Biodiversity Plan should be seen as a positive step, and the replication of these approaches with geodiversity as the main focus could be seen as the next step in the evolution of natural heritage conservation.

6 Conclusions and Recommendations

The Jersey geodiversity audit provides a comprehensive assessment of the geoheritage and geodiversity sites in Jersey. Through the audit, a further 11 sites have been proposed for consideration as Geological SSIs. These comprise sites that provide important contributions to the understanding of the geological history of Jersey, as well as the surrounding northern European region. Actions to protect these sites will help to preserve records of geological materials and processes to inform ongoing research, support the study of Earth science and encourage public engagement.

In addition to the proposed SSIs, nine 2nd Tier sites are identified that have regional and local importance, and they could be recognised as Regionally Important Geological Sites (RIGS). The recognition of three Special Landscape Areas (SLAs) may also contribute to geoconservation efforts. SLAs could include policies for landscape features with characteristics and qualities of local significance. These could be non-statutory designations that define local areas of high landscape importance that may be unique, exceptional or distinctive. SLAs could apply where there is good reason to believe that normal planning policies cannot provide the necessary protection.

Within the contexts of specific sites, observations reflecting potential actions that could be taken to enhance a site's accessibility or condition have been made in the accompanying site reports, and these may be used to help identify potential management approaches for enhancing the geodiversity and geoheritage of existing and proposed sites.

The conservation of archaeological remains and sediments and their settings should be a consideration in planning applications. Where archaeological remains are known (listed as SSIs) or where there is a potential for them to occur, as defined by mapped Quaternary deposits, applications for development should be accompanied by geoarchaeological input into desk-based evaluations, leading to geoarchaeological evaluations of potential where necessary. Going forward, it is proposed that a series of high-level Prehistoric Landscape Zones (PLZs) are properly defined and added to the Historic Environment Record. The extent and nature of each of the PLZs can then be updated as the collective understanding of this topic progresses.

As highlighted in Section 5 of this report, a range of approaches can be adopted to support efforts for geoconservation, ranging from developing or enhancing existing policy instruments and using legislative frameworks to facilitating community and local interest groups.

The development of a Geodiversity Strategy, building on the existing Biodiversity Strategy, and the results of this audit may provide a useful mechanism for facilitating geoconservation in Jersey at a variety of levels. As in the case of the Biodiversity Strategy, a new Geodiversity Strategy could provide a basis for the development of a Geodiversity Action Plan at a local or jurisdictional level.

Advantages of the action plan approach include the recognition and development of provisions for longer-term monitoring and the re-evaluation of sites, and the potential for new exposures or features to be recognised and added to the network of sites – reflecting the ongoing influence of the dynamic human and natural processes acting on Jersey's landscape.

In addition to the potential benefits from formal designations and policies, case studies of successful geoconservation approaches in the UK highlight the importance of community involvement, including the coordinated action of local interest groups, societies and education. Engaged communities are critical for ensuring that geoconservation efforts are sustainable and the benefits of geodiversity are realised at the local and community level. Across the UK, engaged community groups and societies take an active role in monitoring and suggesting new sites, and the 'ground-up' approach is an effective means of encouraging interest in geodiversity and conservation in the community. Community groups can also contribute to the regular review of sites to ensure safe access to sites and features of interest.

7 Geological SSI Reports

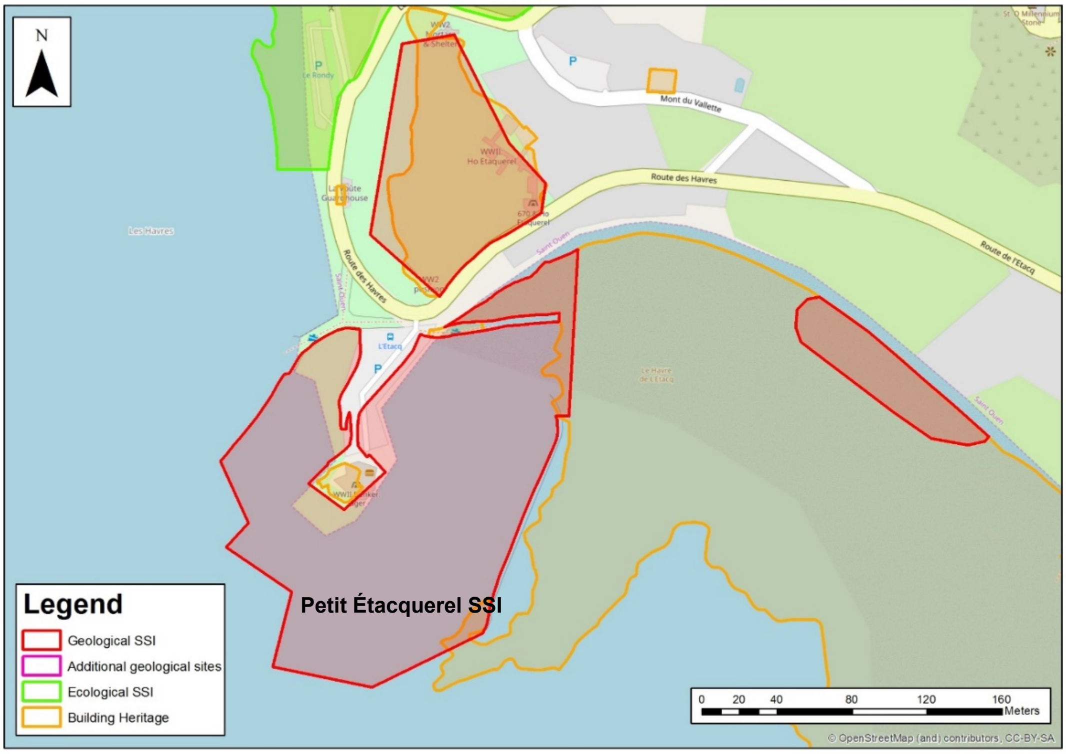
7.1 SITE NAME: PETIT ÉTACQUEREL, SSI

Site Information:

This site comprises an intertidal area of outcrops around the headland at L'Etacq in the northern part of St Ouen's Bay. The bedrock is part of the *Jersey Shale Formation*, which here contains a range of internal structures that demonstrate its deposition, as turbidites, in the lower part of the middle to outer sections of a submarine fan that formed roughly 587 million years ago. Sediments deposited in other parts of this fan can be seen at Grand Étacquerel and at sites in St Peter's Valley.

National Grid Reference: Mid-point: 31684.158, 71647.476 West end: 31584.83, 71662.246 East end: 31750.255, 71659.662	**Site Type:** Natural section/exposure
Site Ownership: Public	**Current Use:** Open country
Field Surveyors: RS Kendall and S Arkley	**Current Geological Designations:** Geological SSI
Date Visited: 23 and 26 September 2019	**Other Known Designations:** Eastern boundary overlaps with St Ouen's Peat Beds (Folio No OU0227). Petit Étacquerel Slipway (Folio No OU0122) and German Occupation Site: Casemate, Strongpoint L'Etacquerel (Folio No OU0042) are within but excluded from the Geological SSI. Within National Park boundary.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran (late Precambrian)	**Formation:** *Jersey Shale Formation*
Rock Types: Sandstone, siltstone and claystone with rare intra-formational conglomerates	

Site Description:

Introduction

This site comprises an intertidal area of outcrops around the headland at L'Etacq in the northern part of St Ouen's Bay. The bedrock is part of the *Jersey Shale Formation*, which was deposited in a submarine fan that formed roughly 587 million years ago on an Andean-type continental margin and was folded and weakly metamorphosed during this orogenic event (Helm and Pickering, 1985; Bishop and Bisson, 1989).

This site at Petit Étacquerel provides an opportunity to examine the lower part of the middle to outer section of this extensive fan. Other parts of the fan can be seen in exposures at Grand Étacquerel and St Peter's Valley.

Bedrock Units

Jersey Shale Formation

The *Jersey Shale Formation* is estimated to be 2500 m thick and consists of the oldest rocks exposed in Jersey. They mainly comprise cycles of mudstones, siltstones, sandstones and minor conglomerates, known as turbidites, which have subsequently undergone low-grade regional metamorphism and have been affected by tectonic processes (Bishop and Bisson, 1989). Carbon flakes up to 10 mm across have been recorded by various authors (e.g., Mourant, 1940; Robinson, 1960).

Turbidites are sedimentary deposits that are genetically related to subaqueous sediment gravity flows in which fluid turbulence is the principal particle support mechanism (also known as turbidity currents). A turbidity current is generated due to the contrast between the density of the flow entering the basin (water-sediment mix) and the density of the water within the receiving basin. Turbidity currents can be triggered by earthquakes and storms or may simply be related to variable fluvial input into bodies of water during climatic fluctuations on land or changes in the relative sea level (marine or even deep lacustrine). They often form as a series of subaqueous fan systems on the basin floor. A detailed study of the *Jersey Shale Formation* was made by Helm and Pickering (1985): they identified six sedimentary facies, which they grouped into four facies associations. These represent deposition in different regions within the submarine fan: I – canyon or inner fan channel fill, II – middle fan channel fill, III – lower fan / outer fan deposits and IV – outer fan deposits.

The lithologies and sedimentary structures seen in the rocks exposed at Petit Étacquerel indicate that they were deposited in shallow ephemeral channels with some interchannel and/or fan-fringing deposits. These features are typical of those found in the lower part of the middle to outer sections of the submarine fan (Association III, Helm and Pickering, 1985).

Sedimentary features, readily examined at Petit Étacquerel, include ripple-laminated, very fine-grained sandstones and graded medium- to fine-grained sandstones, which show the sequence of internal structures typical of deposition from relatively high-density turbidity currents (under a water current flowing swiftly downslope because of the weight of the sediment it is carrying; Bouma, 1962). The rocks also display the effects of soft-sediment, post-depositional liquefaction and flow in the form of distorted cross-laminae and cross-cutting sedimentary dykes.

Evidence of the direction of flow (palaeocurrent) can be measured from current ripples, which indicate flow towards the north-north-west. Flute casts on the bases of sandstone units also suggest flow towards the north.

Helm and Pickering (1985) suggest that the *Jersey Shale Formation* becomes progressively younger in age to the east and was constructed from northerly directed sediment gravity flows; they concluded that the formation probably represents submarine-fan deposition on a continental margin, consistent with deposition on a basin perched on a continental slope adjacent to a volcanic arc above a subduction zone, as suggested by the plate tectonic reconstructions of Dewey (1969) and Mitchell and Reading (1971).

Structures
During the Cadomian Orogeny, the *Jersey Shale Formation* was folded and weakly metamorphosed. Much of the evidence for this can be found across St Ouen's Bay and can be examined at Petit Étacquerel and the area to the south.

Helm (1983, 1984) describes two main phases of deformation, represented by folds and axial plane fabrics. The early (D_1) folds are simple, singly plunging folds or doubly plunging periclines (dome- or trough-shaped), with typical axes trending from WNW–ESE through N–S to NE–SW. The periclines are generally asymmetrical, open to close, and gently plunging with a westerly vergence, but they can be upright and verge towards the east. The singly plunging D_1 folds sometimes have a relatively strong, spaced, axial-planar cleavage, suggesting that they are parasitic in the eastern limb of a major D_1 anticline. Helm thought that the more complex D_1 periclines probably represented early-forming non-cylindrical buckles associated with variations in lithology. Helm identified D_2 structures that produced major folds, a non-penetrative, axial-planar fabric and a system of conjugate shear faults. Helm also noted that both D_1 and D_2 folds are overprinted by a system of late, radial fractures, which he attributed to the vertical stress associated with the rising basaltic magma that infills some of the fractures. He also thought that the occurrence of a closely spaced N–S joint might indicate yet another, fourth deformation and noted that a similar fabric exists in the adjacent North-west granite complex.

Age and regional correlation
Miller *et al.* (2001) produced a uranium-lead isotope date for the *Jersey Shale Formation*. The youngest zircons yielded nearly concordant dates of 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma, providing a maximum depositional age for the unit. They also tested zircons from the overlying volcanic rocks (Anne Port Rhyolite), which had an upper intercept date of 582.8 +3/-2.7 Ma; this is considered to be the date of eruption. These dates provide good constraints on the age of the *Jersey Shale Formation*.

The *Jersey Shale Formation* has been correlated with the Upper Brioverian rocks of the Baie de St Brieuc and La Manche regions of France on the basis of lithological studies (e.g., Graindor, 1957; Dupret *et al*., 1990; Guerrot *et al*., 1989). The Brioverian, in France, is divided into upper and lower sequences, with the Coutances quartz diorite used as a regional time marker (584 ± 4 Ma; Guerrot *et al*., 1989), as it intrudes and metamorphoses the older sequence but not the younger. However, Miller *et al.* (2001) have produced a minimum date for the formation; this date indicates that its deposition occurred at or after *c.* 587 Ma, which may suggest that the *Jersey Shale Formation* should be placed in the Lower Brioverian. Alternatively, it may be that the deposition and deformation of the Brioverian volcano-sedimentary sequence was diachronous, which would mean that these lithological and age relationships cannot be applied across the whole region (Miller *et al*., 2001).

Quaternary Sediments and Landforms
There is a good view south and east from L'Étacq across St Ouen's Bay. At the back of the bay, there is an abandoned cliff in the North-west granite complex. Compared to the Jersey Shale Formation, the granite is more resistant to erosion and forms a distinctive line of cliffs. The base of the cliff is 20–25m above the present mean sea level and is topped by a peneplained surface at about 65 m. The shape of St Ouen's Bay is in part the result of the *Jersey Shale Formation* rocks being eroded and forming low ground, which is covered in Holocene blown sand. Underlying peats have been dated to 4,000 BP, and at extremely low tides, a submerged forest, which includes stumps of alder and hazel, can sometimes be seen. Hazel nuts, animal bones and pottery have also been found here (Bishop *et al*., 2003).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Good access from small car parks along the coast between Faulkner Fisheries and Le Pulec

Safety of access	There is easy access to the shore but all visitors should be aware of the tide times when planning a visit, as many of the exposures are only visible at low tide.
Safety of exposure(s)	The rocky foreshore exposures are uneven and the rocks are also slippery when wet. There are often deep accumulations of seaweed, which hide holes.
Access	Along foreshore and via slipways
Current condition	Some of the exposure is obscured by barnacles and seaweed below the high-water mark. Above the high-water mark, rocks can be obscured by patches of lichens.
Current conflicting activities	This site is bordered by other conservation designations, although their presence is not thought to impact the site.
Restricting conditions	Tide: Much of the exposure is within the intertidal zone and therefore covered at high tide.
Nature of exposure(s)	Intertidal rocky outcrop with some low cliff exposure

Assessment of Site: Cultural, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Site of Le Havre Tower: built *c.* 1832, demolished 1940s. This SSI surrounds Petit Étacquerel Slipway (listed building, OU0122), which dates from the 1860s (HER Number 0900122).
Aesthetic landscape	Coastal landforms
History of Earth science	None
Economic geology	None

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy	International	Excellent	Detailed	X
Sedimentology	National	Good	Detailed	X
Igneous/mineral/meta				
Structural geology	Local	Moderately good	Detailed	
Palaeontology				
Geomorphology	Local	Moderately good	Descriptions	

Geoscientific Value of the Site
The geoscientific value of this site lies in its accessibility; the site provides access to the sedimentary and lithological features associated with part of a submarine fan and the turbidite deposits within the *Jersey Shale Formation*. Along with other sites in this formation at Grand Étacquerel and St Peter's Valley, this site provides an opportunity to contrast the different styles of sedimentation in different parts of the fan. This is also a good place to examine the Cadomian deformation of rocks. This site is a great place for educational groups, as the geology is readily accessible and demonstrates a range of features.

Assessment of Site: Current Site Usage	
Community	The shoreline is used by locals for general outdoor recreation purposes.
Education	The site displays a variety of features: geologists and other interested parties can examine the range of features associated with turbidites, and the site is an excellent locality for educational fieldwork. The site could benefit from the production of geological leaflets that highlight the interesting features at this site, a geotrail and interpretation boards.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	This site has been vandalised, with boulders, which are reputed to be some of the best places to see features, being removed from the beach. Geological vandalism is also evident in terms of hammering and cores and so the site would benefit from protection from further damage.
Potential use	This site could be used as part of a geotrail or for school trips and higher education and research.

Site Photos:

Photo 1: General view of the northern part of the site, facing towards the NNW, showing cycles of turbiditic mudstones, siltstones, sandstones and minor conglomerates, which have subsequently undergone low-grade regional metamorphism, turning the siltstones a purplish colour, and have been affected by tectonic processes associated with the Cadomian Orogeny. BGS © UKRI 2020.

Photo 2: Cycles of very thin to thin-bedded, very fine-grained, normally graded sandstones with ripple lamination (Facies II, Helm and Pickering, 1985), suggesting deposition from low-density, low-velocity turbidity currents. BGS © UKRI 2020.

Photo 3: The thicker lens-shaped, sandstone units seen here are normally graded, thickly bedded (up to 1 m thick), medium- to fine-grained sandstone beds.

(Facies III, Helm and Pickering, 1985). BGS © UKRI 2020.

Photo 4: Millimetre-scale sandstone injectite, cutting bedding. Metre-scale sedimentary dykes are also seen here, cross-cutting bedding, close to the slipway in the eastern part of the site. View faces east. BGS © UKRI 2020.

Photo 5: Ripple crests seen in the bedding surface of a fine-grained sandstone, close to the slipway in the eastern part of the site. View faces east. BGS © UKRI 2020.

Photo 6: Soft-sediment deformation that occurred during the early stages of sediment consolidation. BGS © UKRI 2020.

Photo 7: Small-scale faults developed in fine-grained sandstone and siltstones in response to overpressure during sediment consolidation. BGS © UKRI 2020.

Photo 8: Ripples developed in fine sandstones. BGS © UKRI 2020.

Photo 9: Intra-formational conglomerate in thick, m-scale sandstone beds to the north of Faulkner Fisheries. View faces north. BGS © UKRI 2020.

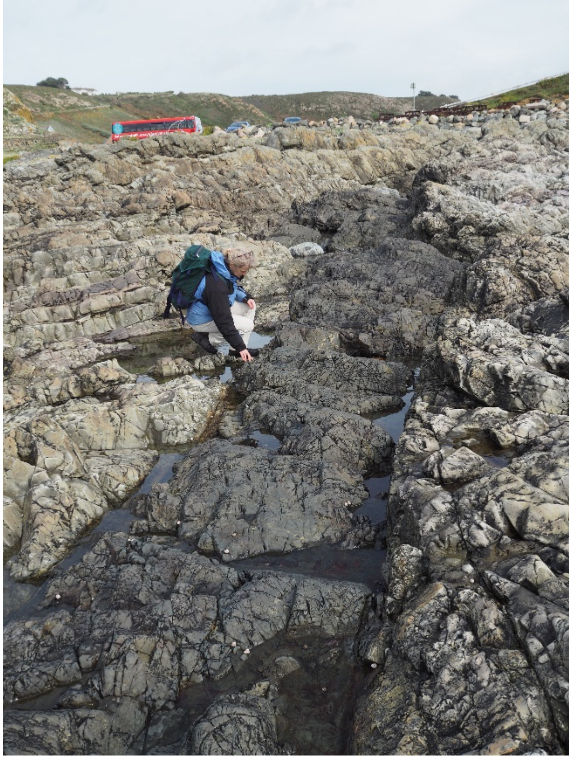
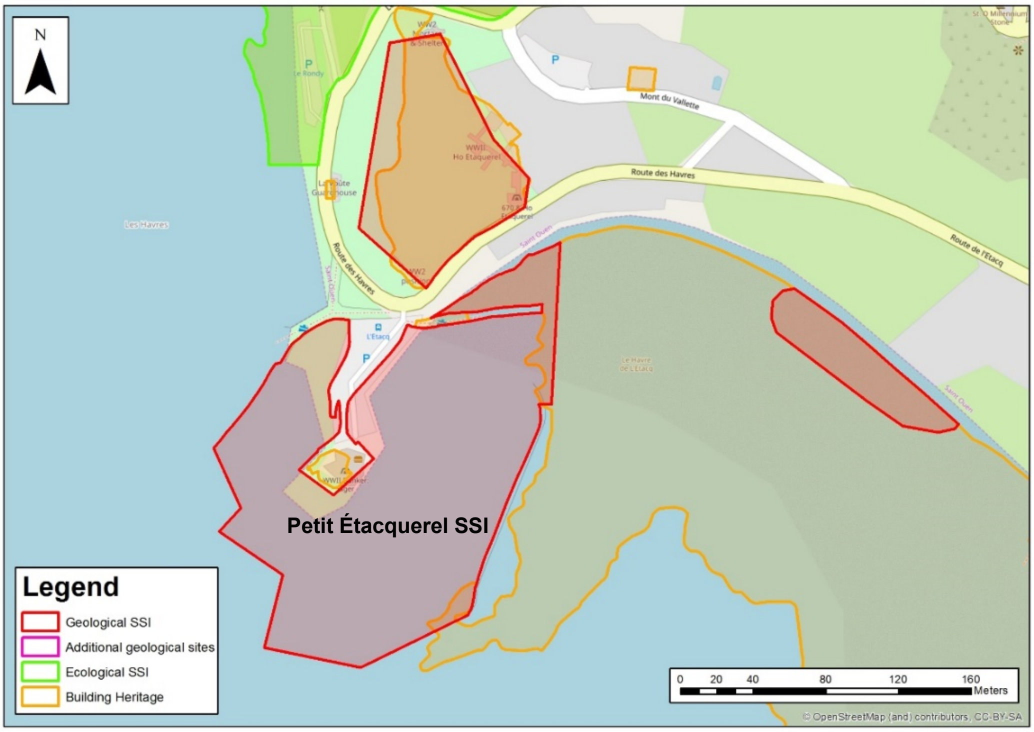


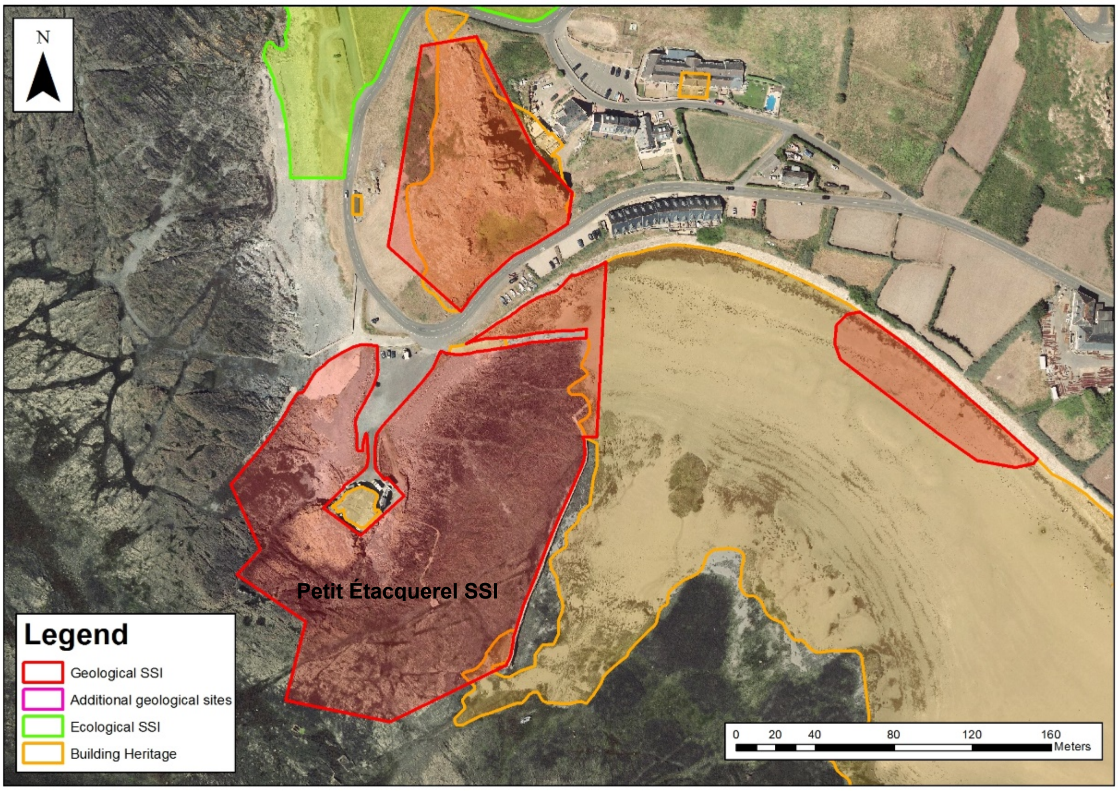
Photo 10: A basaltic dyke intruding the *Jersey Shale Formation* to the north of Faulkner Fisheries. View faces south-east. BGS © UKRI 2020.

Map of the site boundary on a topographic base



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

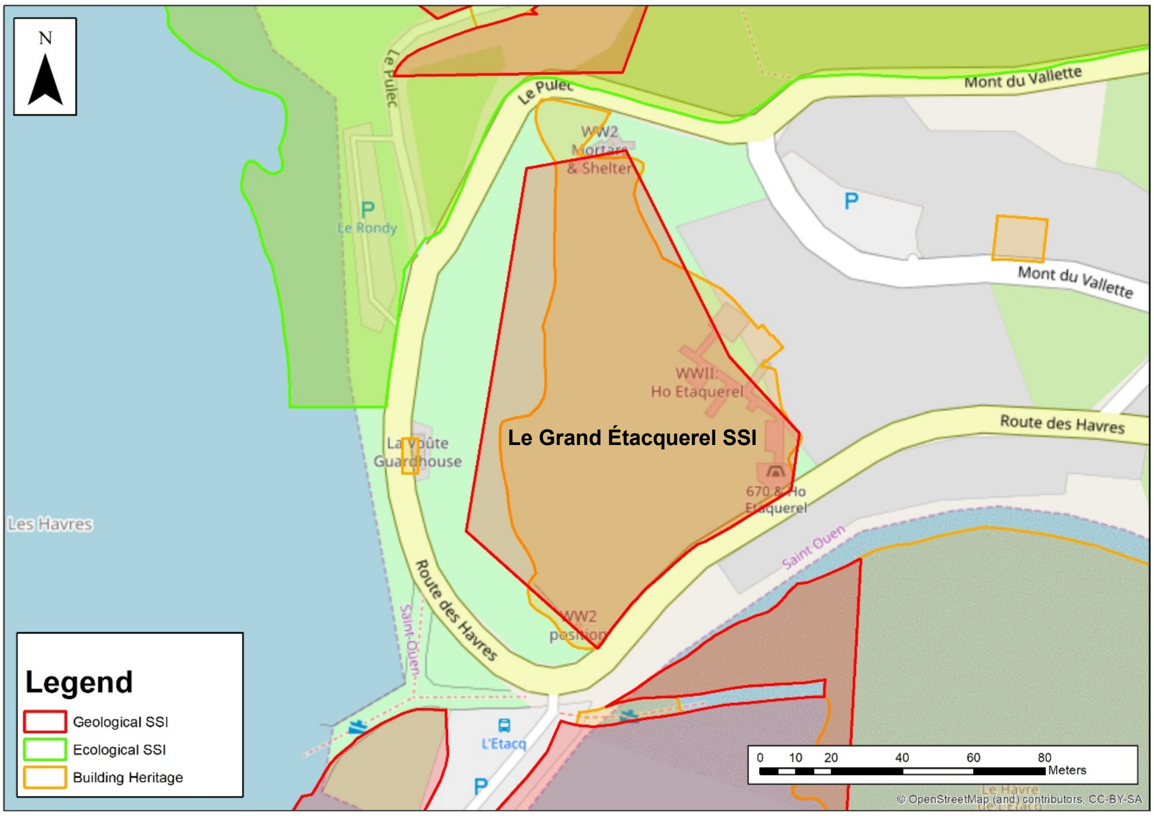
Map of the site boundary on a published geological map

Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.2 SITE NAME: GRAND ÉTACQUEREL, SSI

Site Information: This site comprises much of the headland at L'Etacq in the northern part of St Ouen's Bay. The bedrock is part of the *Jersey Shale Formation*, which here contains a range of internal structures that demonstrate its deposition, as turbidites, in the outer parts of a submarine fan that formed roughly 587 million years ago. Sediments deposited in other parts of this fan can be seen at Petit Étacquerel and at sites in St Peter's Valley.	
National Grid Reference: Mid-point: 31684.158, 71647.476 West end: 31584.83, 71662.246 East end: 31750.255, 71659.662	**Site Type:** Natural section/exposure
Site Ownership: Private	**Current Use:** Open country, coastal
Field Surveyors: RS Kendall and S Arkley	**Current Geological Designations:** Geological SSI
Date Visited: 23 and 26 September 2019	**Other Known Designations:** To the north and at the north-west boundary is Les Landes Ecological SSI and Les Landes Prehistoric Landscape (OU0175). Étacquerel La Votte (Listed building OU0171; HER Number 0900171) is to the west of the SSI. Strongpoint L'Etacquerel (HER Number 0900041; Listed building, OU0041/OU0042).

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran (late Precambrian)	**Formation:** *Jersey Shale Formation*
Rock Types: Sandstone, siltstone and claystone with rare intra-formational conglomerates and rare tuff	

Site Description:

Introduction

This site comprises outcrops around the headland at L'Etacq in the northern part of St Ouen's Bay. The bedrock is part of the *Jersey Shale Formation*, which was deposited as turbidites in a submarine fan on an Andean-type continental margin; the fan formed 587 million years ago and was folded and weakly metamorphosed during the Cadomian orogenic event (Helm and Pickering, 1985; Bishop and Bisson, 1989). This site at Grand Étacquerel provides an opportunity to examine the outer section of this extensive fan. Other parts of the fan can be seen in exposures at Petit Étacquerel and St Peter's Valley.

Bedrock Units

Jersey Shale Formation

The *Jersey Shale Formation* is estimated to be 2500 m thick and consists of the oldest rocks exposed in Jersey. It mainly comprises cycles of mudstones, siltstones, sandstones and minor conglomerates, which were deposited as turbidites and have subsequently undergone low-grade regional metamorphism and been affected by tectonic processes (Bishop and Bisson, 1989).

Turbidites are sedimentary deposits that are genetically related to subaqueous sediment gravity flows in which fluid turbulence is the principal particle support mechanism (also known as turbidity currents). A turbidity current is generated as a result of a contrast between the density of the flow entering the basin (water-sediment mix) and the density of the water within the receiving basin. Turbidity currents can be triggered by earthquakes and storms or they may simply be related to variable fluvial input into bodies of water during climatic fluctuations on land or changes in the relative sea level (marine or even deep lacustrine). They often form as a series of subaqueous fan systems on the basin floor. A detailed study of the *Jersey Shale Formation* was made by Helm and Pickering (1985); they identified six sedimentary facies, which they grouped into four facies associations. These associations represent deposition in different regions within the submarine fan: I – canyon or inner fan channel fill, II – middle fan channel fill, III – lower fan / outer fan deposits and IV – outer fan deposits.

The lithologies and sedimentary structures seen in the rocks exposed at Grand Étacquerel are typical of those deposited in the outer sections of a submarine fan (Association IV, Helm and Pickering, 1985) and are best examined in road cuts along its southern margin and the small quarry in the south-western part of the site. Similar features can be examined in the crags, but they are much obscured by lichens. Facies Association IV is the most important in terms of area and volume out of all of the associations seen within the *Jersey Shale Formation* and consists of laminated mudstone, ripple-laminated and very fine-grained sandstone and cross-stratified medium-grained sandstone. The sandstone bed thickness and coarseness increases upwards in cycles with a corresponding increase in the ratios of sand to mud. At Grand Étacquerel, three such cycles can be examined. This is best seen from the beach, looking north towards the southern margin of the site (Photo 2).

Evidence of the direction of flow (palaeocurrent) can be measured from current ripples, which indicate flow towards the north-north-west. Flute casts on the bases of sandstone units also suggest flow towards the north. There are good examples of these flute casts in the small quarry in the south-west part of the site.

Helm and Pickering (1985) suggested that the *Jersey Shale Formation* becomes progressively younger towards the east and was constructed from northerly directed sediment gravity flows. They concluded that the formation probably represents submarine-fan deposition on a continental margin, which is consistent with deposition on a basin perched on a continental slope adjacent to a volcanic arc above a subduction zone, as suggested by the plate tectonic reconstructions of Dewey (1969) and Mitchell and Reading (1971).

Structures

During the Cadomian Orogeny, the *Jersey Shale Formation* was folded and weakly metamorphosed. Much of the evidence for this can be found across St Ouen's Bay and can be examined at Petit Étacquerel and in the area to the south.

Helm (1983, 1984) described two main phases of deformation, represented by folds and axial plane fabrics. The early (D_1) folds are simple, singly plunging folds or doubly plunging periclines, with a typical axis trending from WNW–ESE through N–S to NE–SW. The periclines are generally asymmetrical, open to close, and gently plunging with a westerly vergence, but they can be upright and verge towards the east. The singly plunging D_1 folds sometimes have a relatively strong, spaced, axial-planar cleavage, suggesting that they are parasitic in the eastern limb of a major D_1 anticline. Helm thought that the more complex D_1 periclines probably represented early-forming non-cylindrical buckles associated with variations in lithology. Helm identified D_2 structures that produced major folds, a non-penetrative, axial-planar fabric and a system of conjugate shear faults. Helm also noted that both D_1 and D_2 folds are overprinted by a system of late, radial fractures, which he attributed to the vertical stress associated with the rising basaltic magma that infills some of the fractures. He also thought that the occurrence of closely spaced N–S joints might indicate yet another (fourth) deformation and noted that a similar fabric exists in the adjacent North-west granite complex.

Age and regional correlation

Miller *et al.* (2001) produced a uranium-lead isotope date for the *Jersey Shale Formation*. The youngest zircons yielded nearly concordant dates of 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma, providing a maximum depositional age for the unit. They also tested zircons from the overlying volcanic rocks (Anne Port Rhyolite), which had an upper intercept date of 582.8 +3/-2.7 Ma; this is considered to be the date of eruption. These dates provide good constraints on the age of the *Jersey Shale Formation*.

The *Jersey Shale Formation* has been correlated with the Upper Brioverian rocks of Baie de St Brieuc and the Mache regions of France on the basis of lithological studies (e.g., Graindor, 1957; Dupret *et al*., 1990; Guerrot *et al*., 1989). The Brioverian, in France, is divided into upper and lower sequences, with the Coutances quartz diorite used as a regional time marker (584 ± 4 Ma; Guerrot *et al*., 1989) because it intrudes and metamorphoses the older sequence but not the younger. However, Miller *et al.* (2001) have produced a minimum date for the formation; this date indicates that its deposition occurred at or after *c.* 587 Ma, which may suggest that the *Jersey Shale Formation* should be placed in the Lower Brioverian. Alternatively, it may be that the deposition and deformation of the Brioverian volcano-sedimentary sequence was diachronous, which would mean that these lithological and age relationships cannot be applied across the whole region (Miller *et al.*, 2001).

Quaternary Sediments and Landforms

There is a good view south and east from L'Étacq south across St Ouen's Bay. At the back of the bay, there is an abandoned cliff in the North-west granite complex. Compared to the Jersey Shale Formation, the granite is more resistant to erosion and forms a distinctive line of cliffs in this area. The base of the cliff is 20–25 m above the present mean sea level and is topped by a peneplained surface at about 65 m. The shape of St Ouen's Bay is in part the result of the *Jersey Shale Formation* rocks being eroded and forming low ground, which is covered in Holocene blown sand. Underlying peats have been dated to 4,000 BP, and at

extreme low tides, a submerged forest, which includes stumps of alder and hazel, can sometimes be seen. Hazelnuts, animal bones and pottery have also been found here (Bishop *et al*., 2003).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Good access from small car parks along the coast between Faulkner Fisheries and Le Pulec
Safety of access	There is easy parking directly opposite the south-west part of the SSI. Care should be taken in crossing the road.
Safety of exposure(s)	Most of the clean exposure is along the road, so care needs to be taken when accessing these parts of the site. There are also high cliffs, which can be slippery and are overhanging in places.
Current condition	Along the road and in the small quarry at the south-western corner of the site, the faces are fairly clean; however, higher outcrops are obscured by patches of lichens.
Current conflicting activities	This site is bordered and overlapped by other conservation designations. Any work undertaken at this site should be accompanied by consultation with Jersey Heritage (JH) to consider the overlapping Casemate and Tunnel Complex, STP L'Étacquerel (OU0041) site to ensure its conservation.
Restricting conditions	This site could be extremely slippery in wet conditions and access to some faces may be dangerous due to busy traffic.
Nature of exposure(s)	Roadside cuttings, small quarry and headland crags

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	La Votte (listed building OU0171; HER Number 0900171) to the west of the SSI. Strongpoint L'Étacquerel (HER Number 0900041; listed building, OU0041/OU0042)
Aesthetic landscape	Headland
History of Earth science	None
Economic geology	None

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy	Regional	Good		X
Sedimentology	Regional	Good		X
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology	Local	Good		

Geoscientific Value of the Site
The geoscientific value of this site lies in the easy access it provides to the sedimentary and lithological features associated with the deposition within the outer sections of a submarine fan (Association IV, Helm and Pickering, 1985) of the *Jersey Shale Formation*. Along with other sites in this formation at Petit Étacquerel and St Peter's Valley, this site provides an opportunity to contrast the different styles of sedimentation in different parts of the fan. This is also a useful place to examine the Cadomian deformation of rocks. This site is a great place for educational groups, as the geology is readily accessible and demonstrates a range of features.

Assessment of Site: Current Site Usage	
Community	The headland is used by locals for general outdoor recreation purposes. The site is also of archaeological interest and already attracts visitors for this reason.
Education	The site displays a variety of features, allowing geologists and other interested parties to examine the range of features associated with turbidites, and it is an excellent locality for educational fieldwork if sufficient care is taken with traffic. The site could benefit from the production of geological leaflets that highlight the interesting features at this site, a geotrail and interpretation boards, especially as there is an opportunity here to contrast the site's sedimentary features with those of the adjacent Petit Étacquerel.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Geological vandalism from hammering is evident, so this site would benefit from protection from further damage.
Potential use	This site could be used as part of a geotrail or for school trips and higher education and research.

Site Photos:

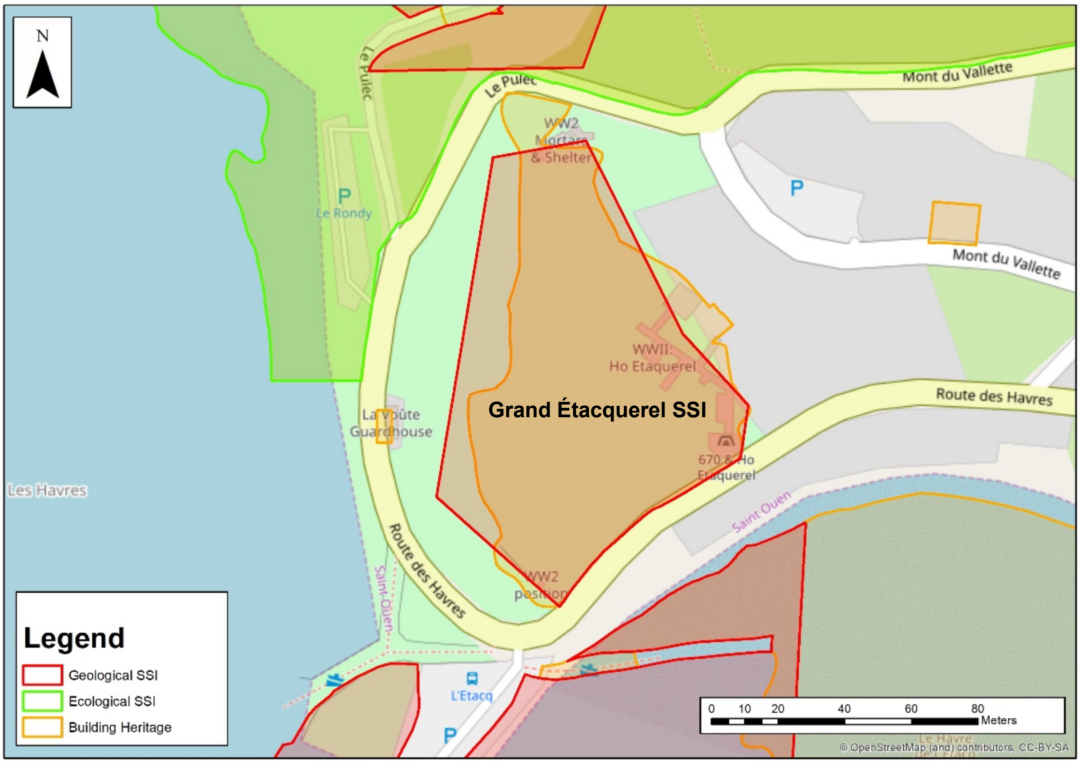
Photo 1: General view of the western part of the site, facing towards the north-east, showing cycles of turbiditic mudstones, siltstones, sandstones and minor conglomerates that have subsequently undergone low-grade regional metamorphism and have been affected by tectonic processes associated with the Cadomian Orogeny. BGS © UKRI 2020.

Photo 2: General view of the outcrop on the southern margin of the site showing the most westerly of the three coarsening-upwards cycles viewable at this site. BGS © UKRI 2020.

Photo 3: Soft sediment deformation in a bed of sandstone in the small quarry at the western end of the outcrop.

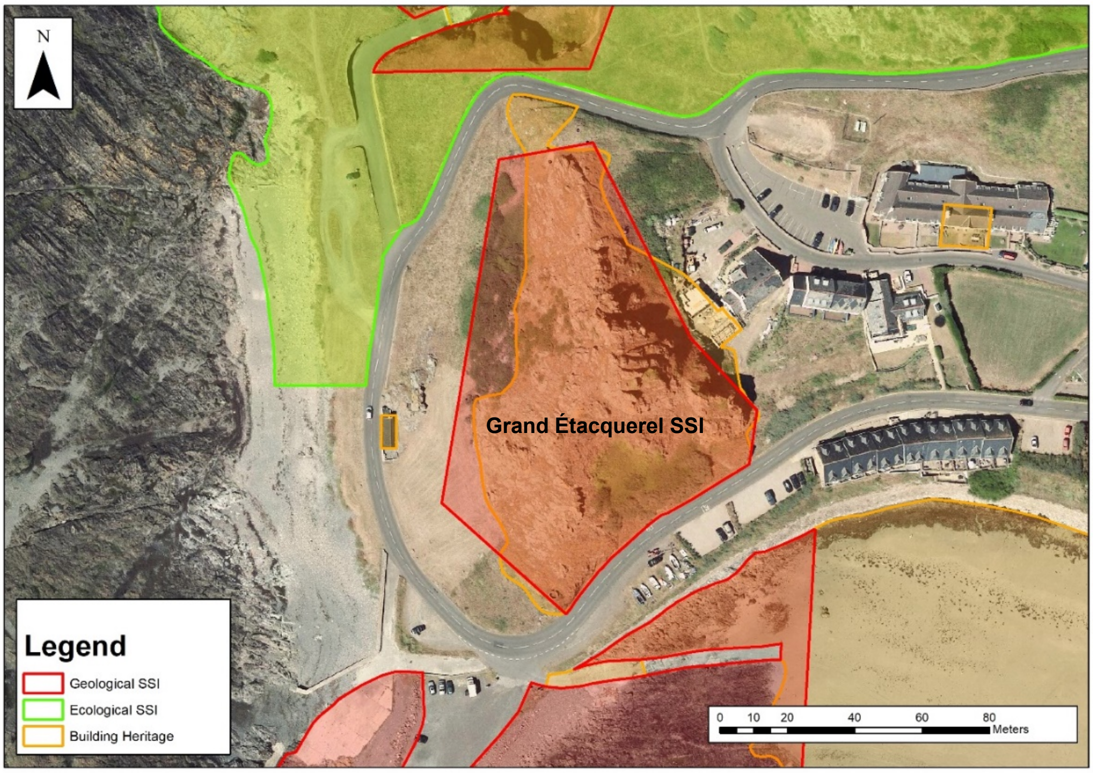
Photo 4: Flute marks on the underside of a bed of fine sandstone. BGS © UKRI 2020.

Map of the site boundary on a topographic base



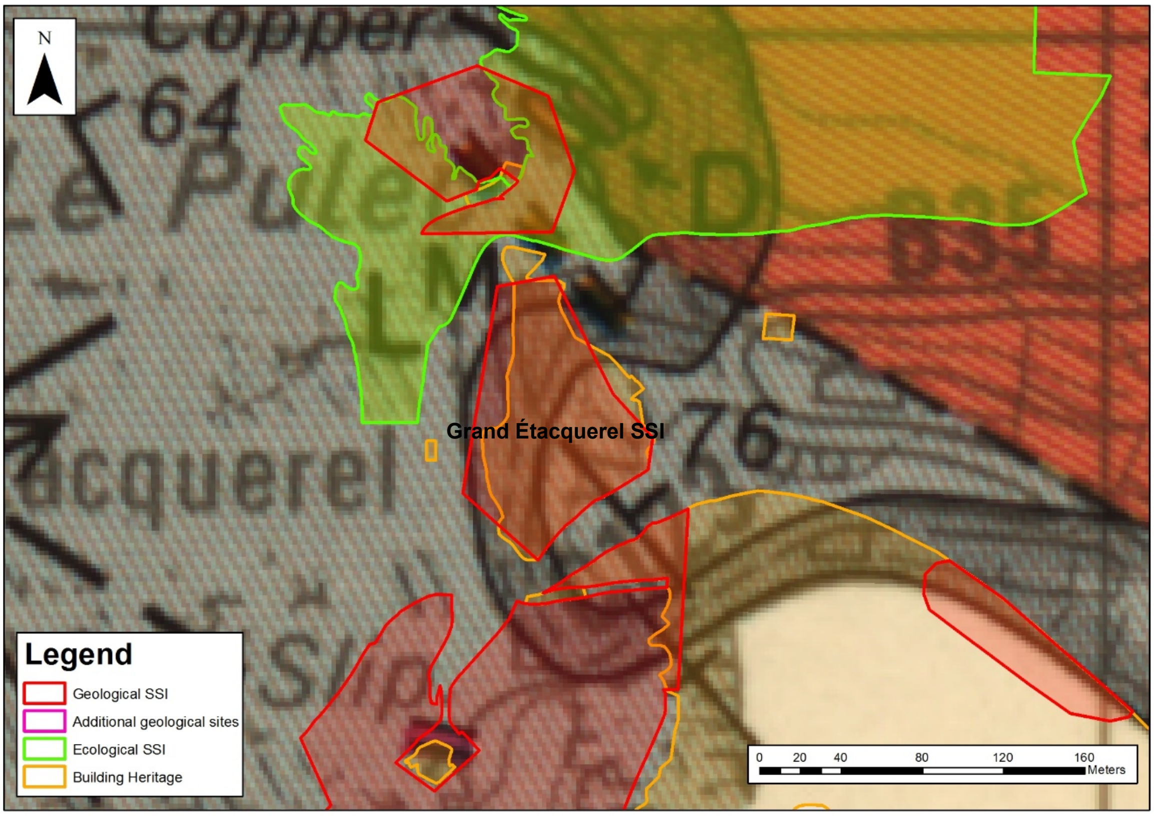
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

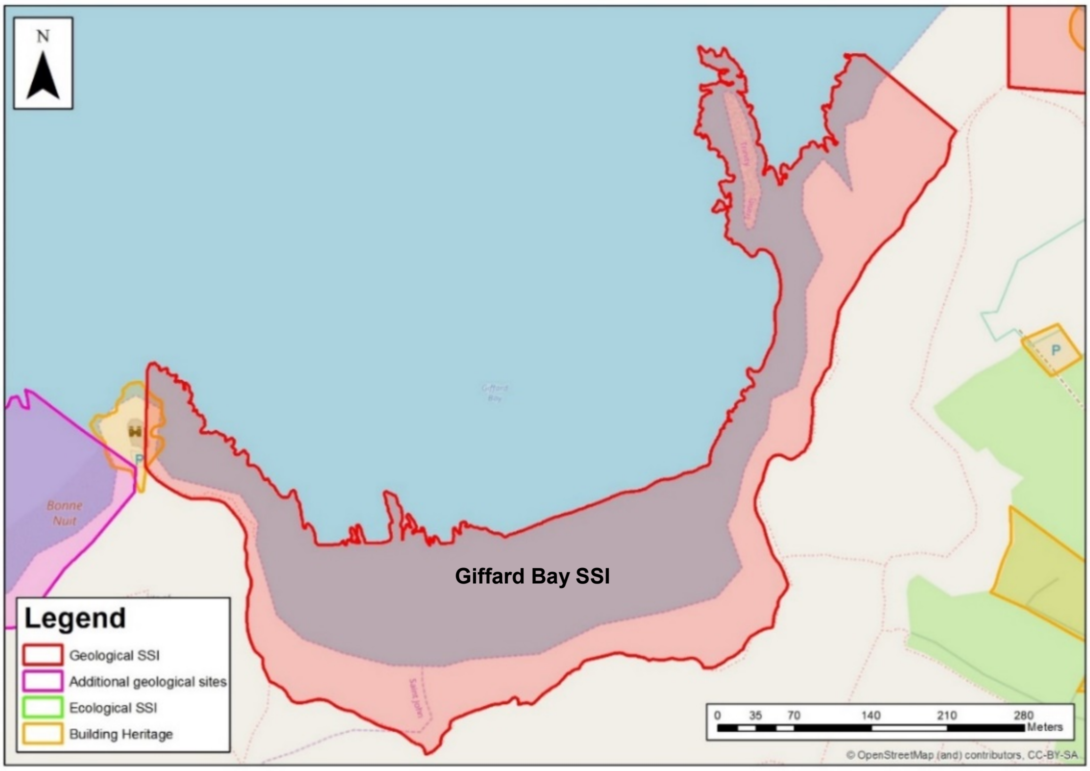
Map of the site boundary on a published geological map



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.3 SITE NAME: GIFFARD BAY, SSI

Site Information:	
Giffard Bay is a coastal site, located in the north of Jersey, where cliffs, promontories and intertidal reefs expose a rock sequence of predominantly extrusive volcanic rocks of the Bouley Rhyolite, St John's Rhyolite and St Saviour's Andesite formations. A faulted contact between the *Jersey Shale Formation* and the Bouley Rhyolite Formation is exposed in the south-east corner of the bay. In the middle of the bay, the Bouley Rhyolite Formation is intruded by a number of lamprophyre dykes. Rhyolite and Andesite lavas, tuffs, agglomerates and conglomerates of the St Saviour's Andesite Formation are exposed in a complex series of fault-bound slices in the cliffs and promontories between the Long Echet and the south-east corner of Giffard Bay. Pebbly beach gravel of the 8 m raised beach is overlain by >8 m of boulder head in cliffs behind the rock promontory backing the middle part of the site. Great care needs to be taken accessing this site due to the risk from high tides and uneven ground.	
National Grid Reference: Mid-point: 42141, 72895 West end: 41696, 72924 East end: 42437, 73230	**Site Type:** Natural section/exposure
Site Ownership: Private	**Current Use:** Open country, coastal
Field Surveyors: S Arkley and C Auton	**Current Geological Designations:** Geological SSI: Giffard Bay (Local A)
Date Visited: 13 and 14 October 2019	**Other Designations:** Building Heritage: La Crête Fort (JN0138) overlaps with the western end of the site. Other: Areas above the high water mark (HWM) are within the Jersey National Park.
Site Map	



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: (Ediacaran Period) late Precambrian	**Formation:** *Jersey Shale Formation*
Rock Types: Sandstone, siltstone and claystone	
Age: (Ediacaran Period) late Precambrian	**Formation:** St Saviour's Andesite Formation
Rock Types: Andesite, agglomerate, tuff, mudstone and conglomerate	
Age: (Ediacaran Period) late Precambrian	**Formation:** St John's Rhyolite Formation
Rock Types: Rhyolitic ignimbrite and agglomerate	
Age: (Ediacaran Period) late Precambrian	**Formation:** Bouley Rhyolite Formation
Rock Types: The following principal units have been identified within the Bouley Rhyolite Formation at this site: Giffard Andesite; Giffard Ignimbrite; Giffard Tuff; Giffard Rhyolite; Giffard Andesitic Agglomerate; Les Platons Rhyolite.	
Age: Cambrian to Ordovician	**Formation:** Dykes
Rock Types: Dolerite	
Age: Silurian	**Formation:** Dykes
Rock Types: Lamprophyre	
Age: Quaternary	**Formation:** Raised beach
Rock Types: Clast-supported, well-rounded pebble gravel in a matrix of yellow silty sand	
Age: Quaternary	**Formation:** Head
Rock Types: Poorly sorted and weakly stratified deposit containing angular blocks of local bedrock	

Site Description:

Introduction

Giffard Bay is a coastal site backed by steep vegetated cliffs cut in head deposits, with restricted access from the lower coastal path from La Crête Fort to the rock headlands and platforms at the western end of the site via two steep narrow paths down the cliff (Photo 1). Access to the middle part and eastern end of the site is limited to a short period of time during low tide. All access requires scrambling over steep and sometimes hazardous rock surfaces.

The volcanic rocks at the Giffard Bay site are part of the *Jersey Volcanic Group* and were formed during the Ediacaran Period (late Precambrian). They are one of the three principal known occurrences of calc-alkaline volcanic rocks associated with the Cadomian orogenic belt of North-west France and the adjacent Channel Islands (Lees and Roach, 1993), with the sequences in Jersey being the best exposed of the three. The other occurrences are the Tufs de Trêguier and Ignimbrites de Lêzardrieux in Brittany (Auvray, 1989) and the Serie volcano-sedimentaire et complexe ignimbritique de St Germain-le-Gaillard in Normandy (Graindor, 1957; Graindor *et al*., 1976). The *Jersey Volcanic Group* is divided into three formations: the St Saviour's Andesite Formation (oldest), St John's Rhyolite Formation and Bouley Rhyolite Formation (youngest).

The geology exposed in Giffard Bay is complex, and at this locality the typical Ediacaran succession exposed elsewhere in Jersey is strongly disrupted by faults (see the published geological map from IGS [1982] for details). In very general terms, the western side of the bay comprises ignimbrites of the St John's Rhyolite Formation, which pass upward to the east into various units of the Bouley Rhyolite Formation. The south-east part of the bay is transected by the WNW-trending Frémont Fault. Immediately adjacent to this to the north, exposed in a splay of the Frémont Fault, shales of the *Jersey Shale Formation* are brought up in a narrow slice. Immediately to the north-east of this, toward Belle Hougue Point, is a strongly disrupted succession of the *Jersey Shale Formation* passing upward into the St Saviour's Andesite Formation lithologies that make up much of the foreshore exposure toward the eastern part of the bay.

None of the exposures of the St Saviour's Andesite Formation and *Jersey Shale Formation* in the cliffs and promontories between Long Echet and the south-east corner of the bay were examined during the site visit because of the hazardous nature of the exposures.

Bedrock Units

St John's Rhyolite Formation (Jersey Volcanic Group)

At Giffard Bay, the St John's Rhyolite Formation is only represented by the Frémont Ignimbrite, which is exposed at the western margin of the site to the east of La Crête Fort (Thomas, 1977). This sequence comprises a flow-banded ignimbrite (Photos 2 and 3) overlain by a bed of agglomerate, which separates the Frémont Ignimbrite from the Giffard Rhyolite at the base of the overlying Bouley Rhyolite Formation (figure 11 of Bishop and Bisson, 1989). Mapping undertaken by Thomas (1977) indicates that the Frémont Ignimbrite contains several lenticular bodies of agglomerate (Photo 3). Where it is exposed, the boundary between the St John's Rhyolite Formation and the overlying Bouley Rhyolite Formation dips 45–55 degrees towards the west; this apparent disconformity has been strongly modified by later brittle faulting.

The correlation between the Giffard Rhyolite and the dated Anne Port Rhyolite (U-Pb zircon age of 583 ± 3 Ma; Miller *et al*., 2001) exposed at Anne Port Bay (Thomas, 1977; Bishop and Bisson, 1989) places a potential age constraint on the Frémont Ignimbrite of before *c.* 583 Ma (see below).

St Saviour's Andesite Formation (Jersey Volcanic Group)

The St Saviour's Andesite Formation is exposed close to the north-eastern side of Giffard Bay in the steep cliffs forming the headlands of Long Echet and La Belle Hougue, where it is juxtaposed against rocks belonging to the Jersey Shale and Bouley Rhyolite formations by the Frémont Fault. Due to the difficulty of accessing these rocks from the shore, no additional detailed examination of the St Saviour's Andesite Formation was undertaken during the site visit to Giffard Bay. However, representative field photographs of two of the distinctive rock types (the Vicard Tuff and the Belle Hougue Andesite) that occur in this part of the site, taken by BGS and described by Thomas in 1976, are included in this report (Photos 21 and 22).

To the north of the Frémont Fault, Bishop and Bisson (1989) recognised a further five volcanic rock units, which they called the Vicard Tuff, Long Echet Tuff, Belle Hougue Andesite, Agglomerate Petit Port Andesite and Andesite Undivided (see figure 4 of Bishop and Bisson, 1989). The location of the outcrops of these volcanic rocks has been used to suggest that they may form part of the St Saviour's Andesite Formation.

Bouley Rhyolite Formation (Jersey Volcanic Group)

On the published geological map (BGS, 1982; also, see Bishop and Bisson, 1989), the boundary between the Bouley Rhyolite and *Jersey Shale Formation*s at Giffard Bay is marked by a WSW–ESE-trending fault, the Frémont Fault (Casimir and Henson, 1955), which extends across the foreshore towards L'Homme Mort. The WSW portion of this fault corresponds to a shear zone shown on the map of the foreshore at Giffard Bay published by Bishop and Bisson (1989; figure 10). At Giffard Bay, the Bouley Rhyolite Formation has been subdivided into a six informal, locally named units: the Giffard Rhyolite; Giffard Andesite; Giffard Ignimbrite; Giffard Andesitic Agglomerate; Giffard Tuff; and Les Platons Rhyolite. This volcanic sequence was divided by Bishop and Bisson (1989) into two vertical sections: a *c.* 100-m-thick 'western section' exposed between the La Crête headland and the western end of the pebble beach, and a much thicker, *c.* 250-m-thick 'middle section' exposed on the foreshore, seaward of the pebble beach and on the rocky promontories to the west of the Frémont Fault (see figure 11 of Bishop and Bisson, 1989; see also Casimir and Henson, 1955). However, many of the contacts between many of the volcanic units identified within Giffard Bay are obscured due to the broken-up nature of many of the rock faces, making it difficult to establish the stratigraphical relationships between these units with any degree of certainty.

The Giffard Rhyolite represents the oldest unit within the Bouley Rhyolite Formation that is exposed at the site and possesses a rubbly base and locally exposed (western section only) autobrecciated top. The Giffard Rhyolite locally exhibits well-developed flow banding and folding (Photo 5), as well as spherulites formed due to the devitrification of this glassy volcanic rock (Photo 4). Similar devitrification textures, such as snowflake textures (Photo 7), can be seen in wave-washed cobbles on the beach. The Giffard Rhyolite has been correlated by Thomas (1977) and Bishop and Bisson (1989) with the Anne Port Rhyolite exposed at Anne Port Bay. The Anne Port Rhyolite has yielded a U-Pb zircon age of 583 ± 3 Ma (Miller *et. al.*, 2001). Consequently, if this correlation is correct, it indicates that the remainder of the Bouley Rhyolite Formation exposed at Giffard Bay is younger than *c.* 583 Ma. In the western section, the Giffard Rhyolite is disconformably overlain by the Giffard Andesite (up to 8 m thick) (see figure 11 of Bishop and Bisson, 1989). This andesite has been correlated with the relatively thin (1–3 m thick) Anne Port Andesite exposed at Anne Port Bay (Bishop and Bisson, 1989).

In the western section, the Giffard Andesite is overlain by Giffard Rhyolite, a flow-banded rhyolite flow with a rubbly base. To the east, Bishop and Bisson (1989) suggest that the Giffard Andesite pinches out within the middle section of Giffard Bay, where it is apparently cut out by the irregular rubbly base of the Giffard Ignimbrite (figure 11 of Bishop and Bisson, 1989). However, in the outcrop, the relationship between the Giffard Rhyolite and overlying Giffard Ignimbrite is less clear, as this boundary has been modified by later brittle faulting and fracturing, and/or obscured by seaweed on the foreshore. Locally, however, it can be seen that the Giffard Ignimbrite possesses a eutaxitic texture.

In the middle section of the site, the Giffard Ignimbrite is overlain by Giffard Andesitic Agglomerate, which is in turn overlain by the Giffard Tuff. The agglomerates within both of these units are characterised by the presence of rounded to angular blocks of lava and pumice

(Photos 6 and 13). The Giffard Tuff comprises an interbedded sequence of agglomerates and water-laid tuffaceous sediments that contain locally well-developed sedimentary structures, including bedding, parallel lamination and fine-scale grading (Photos 9–12). This volcaniclastic sequence has been correlated with the Lower Archirondel Tuff, which occurs near the base of the Bouley Rhyolite Formation where it is exposed to the north of Archirondel Tower (Thomas, 1977; figure 13 of Bishop and Bisson, 1989). The youngest unit within the Bouley Rhyolite Formation exposed at the Giffard Bay site is the Les Platons Rhyolite (middle section only), a flow-banded lava that is juxtaposed against rocks of the *Jersey Shale Formation* by the Frémont Fault in the south-east corner of the bay.

Minor sedimentary rock units associated with the Jersey Volcanic Group

Thomas (1977) recognised two other distinctive units associated with volcanic rocks exposed in Giffard Bay: they were called the L'Homme Mort Conglomerate (Photo 19) and the Vicard Mudstone by Bishop and Bisson (1989). Stratigraphically, the conglomerate and mudstone appear to occur between the St John's Rhyolite and the St Saviour's Andesite formations. In the south-east corner of Giffard Bay, the L'Homme Mort Conglomerate is intensely sheared with a well-developed mylonitic texture (Photo 20) as a result of ductile deformation adjacent to the faulted contact with the *Jersey Shale Formation*.

Jersey Shale Formation

The thinly interbedded, olive-brown to grey siltstones, mudstones and fine-grained sandstones assigned to the *Jersey Shale Formation* at the Giffard Bay site are exposed in, and most easily accessed at, the cliffs in the south-east corner of the bay (Photos 14–16). In this area, bedding within these sedimentary rocks dips 32–35° to the SSE. Exposures within the intertidal zone have been smoothed by marine erosion, revealing the finely laminated (banded) appearance of the sandstones, siltstones and mudstones. Sandstone beds range from *c.* 1 cm up to 10 cm in thickness and exhibit both planar conformable and erosional bases. Normal (upward-fining) graded bedding within the sandstones and siltstones indicates that the sequence is the 'right way up' and was not overturned by subsequent tectonic deformation during the Cadomian Orogeny. Small-scale, tight to isoclinal, rootless folds, in particular within the siltier units, are interpreted as being synsedimentary in origin and associated with slumping and mass movement within the sedimentary basin. Sedimentary evidence at Giffard Bay is consistent with the interpretation that the *Jersey Shale Formation* represents a distal turbidite sequence.

The *Jersey Shale Formation* at Giffard Bay occurs in the downthrown block to the east of the Frémont Fault. The exposed rockfaces above the high-water mark are highly fractured by high-angle, conjugate, small-scale faults (Photo 15) with displacements of bedding of a few millimetres to centimetres. Larger-scale fracturing is present locally, giving the rock the appearance of a cemented megabreccia. Thomas (1977) recorded the presence of mylonite and a mylonitic shear zone within the *Jersey Shale Formation* where it is exposed immediately adjacent to the Frémont Fault (see figures 6.3 and 6.13 of Thomas, 1977). Furthermore, several exposures of the *Jersey Shale Formation* have been mapped as fault-bounded bodies within the St Saviour's Andesite Formation where it is exposed in the vicinity of Long Echet (Thomas, 1977; figure 3 of Bishop and Bisson, 1989); these exposures were not visited during this study.

The age of the *Jersey Shale Formation* is provided by the uranium-lead dating of detrital zircons from a sample of sandstone collected from the proximal turbidite sequence exposed at the Grand Étacquerel site. The youngest zircon ages obtained from this detrital assemblage yielded nearly concordant dates of 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma (Miller *et al*., 2001), thereby providing a maximum age for the deposition of at least part of the *Jersey Shale Formation*. The Jersey Shale is also mapped, in apparently un-faulted contact with agglomerate within the St Saviour's Andesite Formation, inland of the Les Rouaux site. If the deposition of the *Jersey Shale Formation* took place at about 587 Ma and the Anne Port Rhyolite (Bouley Rhyolite Formation) was erupted around 583 Ma, the volcanic activity responsible for the eruption of the *Jersey Volcanic Group* occurred between these dates.

Furthermore, Bishop *et al*. (2003) noted that the *Jersey Shale Formation* and the volcanic rocks were folded prior to the emplacement of the South-west granite at *c.* 580 Ma.

Minor intrusions

Three N–S-trending dykes have been mapped cutting the Giffard Rhyolite in the foreshore reef in the middle part of Giffard Bay. One mica lamprophyre and two dolerite dykes were recorded by Bishop and Bisson (1989; figure 10) in this part of the bay; however, only the lamprophyre (Photo 8) and one of the dolerites were exposed during the site visit. Both of these sub-vertical, N–S-trending intrusions are relatively thin (up to 0.4 m thick) and display chilled margins along the rhyolite. Two further intrusions, a NW-SE-trending dolerite dyke occurring parallel to the mylonitic shear zone associated with the Frémont Fault and a N–S-trending lamprophyre dyke, were reported by Bishop and Bisson (1989) on the foreshore in the eastern part of Giffard Bay; however, these were not exposed during the site visit.

Quaternary Sediments

Small exposures of raised beach gravel, resting on the Giffard Bay Andesitic Agglomerate, are present directly beneath >10 m of bouldery head (Photo 23). They are exposed in a cliff above the high-water mark at the back of the middle part of Giffard Bay (Photo 25). These deposits are assigned to the 8 m raised beach. They comprise a clast-supported, well-sorted pebble gravel with a matrix of yellow silty sand (Photo 24) and exhibit a moderately developed clast imbrication. Well-rounded clasts present within the gravel include maroon rhyolite, andesite and other fine-grained volcanic rocks. Flint is present in small amounts and maroon jasper pebbles have also previously been recorded.

The head deposit contains angular blocks of local bedrock, some of which exceed 50 cm in diameter. Although they are generally poorly stratified and weakly sorted, finer-grained beds of water-lain sediment are present just above the contact with the raised beach gravel.

Future Research

The key issue for anyone visiting Giffard Bay is recognising the stratigraphic divisions of the *Jersey Volcanic Group* at the site established by Thomas (1977) and Bishop and Bisson (1989). It is evident from later work by Lees and Roach (1993) that they considered the volcanic rocks to represent an essentially single, continuous sequence passing upwards from units dominated by welded tuffs and andesite lavas in Bonne Nuit Bay, through welded tuffs and tuff breccia at La Crête headland and finally into flow-banded rhyolites and bedded and massive tuffs within Giffard Bay. The marked variation in the number, continuity and distribution of the proposed lithostratigraphic units within the *Jersey Volcanic Group* is clearly illustrated by the geological maps for the area published by Casimir and Henson (1955), Thomas (1977) (reproduced by Bishop and Bisson, 1989) and Lees and Roach (1993). Mourant (1933) interpreted the volcanic rocks at Giffard Bay as being dominated by subaerially erupted lava flows (see also Casimir and Henson, 1955; Lees and Roach, 1993). Subsequently, Thomas (1977) and Bishop and Bisson (1989) argued that many of the units were in fact pyroclastic breccias (agglomerates) and subaerial pyroclastic tuffs and ignimbrite flows. These authors did, however, recognise the presence of some water-lain tuffs, mudstones and conglomerates within the sequence and postulated that some of the mixed units showed signs of being erupted onto wet sediment. In contrast, Lees and Roach (1993), based upon evidence from Bonne Nuit, suggested that much more of the volcanic sequence at Giffard Bay was erupted in a subaqueous environment than had previously been recognised (see the accompanying site description for Bonne Nuit).

In summary, it is clear that the stratigraphy of the *Jersey Volcanic Group* at the Giffard Bay site established by Thomas (1977) and largely followed by Bishop and Bisson (1989) is complex and requires further work (including petrographic and geochemical analysis) to elucidate the eruptive setting of these andesitic to rhyolitic volcanic rocks.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	At La Crête Fort, a sign indicates that parking is only for visitors staying at the fort and not for the general public. Public parking is possible further west by the harbour in Bonne Nuit Bay, to the south of the bay (up the hill) off Le Rue des Platons or to the east near La Belle Hougue viewpoint. However, these are all some distance from the site.
Access to the site	There is open access onto the foreshore at Giffard Bay. If visitors park to the east or west of the site, they can walk along the Jersey Coast Path to La Crête Fort. A short steep path approximately 75 m east of La Crête Fort allows access onto the foreshore.
Safety of access	The Jersey Coast Path, although narrow in places, is in good condition and appears to be well maintained. The short path down onto the foreshore is a slippery cut through the vegetation. Gloves are recommended for the short descent to protect visitors' hands from thorny bushes, especially if the weather has been wet. All visitors should be aware of the tide times and access routes when planning a visit, especially if they wish to visit the outcrops at the eastern end of the site.
Safety of exposure(s)	The cliffs exposing the raised beach and head deposits at the back of the beach appear to be generally stable, but they are high and made of largely unconsolidated material. Visitors would therefore be advised to wear hard hats if they wish to inspect the deposits up close. The intertidal bedrock exposures have an uneven, water-worn surface and are often slippery with algae and seaweed – stout boots are recommended.
Current condition	Some rock exposures are clean and free of vegetation. However, in the intertidal zone, many of the rocks are covered by barnacles, algae and seaweed.
Current conflicting activities	None known
Restricting conditions	Bedrock exposures are dominantly in the intertidal zone and they are therefore covered at high tide. The Quaternary sections, although they lie above the normal high-tide mark, may be difficult to access when the tide is in.
Nature of exposure(s)	Bedrock exposures are found in the intertidal zone and backshore (areas normally above the high-tide mark but washed by the sea during storms). Quaternary deposits can be observed in cliff sections.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	On the headland at the western end of Giffard Bay is La Crête Fort (listed building, JN0138; HER Number 0500138), which was built in 1834 and has German additions from the Second World War.
Aesthetic landscape	Coastal – there are impressive views northwards across to Guernsey, Sark and the French coast on a clear day.
History of Earth science	No known associations
Economic geology	No known associations

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	National	Excellent	Detailed	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The geoscientific value of the Giffard Bay site is considerable, despite the problems of access and safety. It is the only site visited where rocks of all three of the component formations of the *Jersey Volcanic Group* are exposed and where the relationships between them can be examined**.** These rocks comprise one of the principal known occurrences of calc-alkaline volcanic rocks associated with the Cadomian orogenic belt of North-west France and the Channel Islands. Although the volcanic sequences in Jersey, as a whole, are better exposed than those in France, the exposures at Giffard Bay are the most difficult to visit safely. Nevertheless, a wide variety of volcanic units are present, including flow-banded rhyolites, andesites, ignimbrites, tuffs and agglomerates, and a considerable range of volcanic textures can be seen.

Despite the complexity of the Giffard Bay sequences, the correlations proposed for several of the units within the Bouley Rhyolite Formation at Giffard Bay with similar volcanic sequences at other sites (notably Anne Port) are key to understanding the lithological similarities and age differences between these sequences. The exposure of a distal turbidite facies of the Jersey Shale in the south-east corner of the site is also important, as it clearly illustrates the tectonic (faulted) contact between the *Jersey Volcanic Group* rocks and the older turbidites.

Assessment of Site: Current Site Usage	
Community	La Crête Fort has been renovated and is now used as a holiday let for visitors to the Island by Jersey Heritage. The Jersey Coastal Path, which runs along the edge of the bay (although at some height above the beach), is frequently used by locals and tourists; however, few people are thought to go down onto the foreshore. There is no café and no toilets at the site.
Education	The geoscientific value of the Giffard Bay site is considerable. All three formations of the *Jersey Volcanic Group*, which include a whole variety of volcanic lithologies and structures, can be observed here. Although the relationships between the units are often complex and difficult to determine, the polished beach pebbles are fantastic for displaying the variety of lithologies and structures in the volcanic succession for younger or less knowledgeable visitors. The opportunity to additionally examine the relationships between the units will be of great interest for higher education and research groups.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Like all coastal locations, the site is subject to high-energy weathering and erosion. However, the bedrock exposures are fairly robust. The cliff sections at the back of the beach are largely above high tide. Some washing and minor erosion of the cliffs by storm waves probably helps in keeping the sections exposed (free of vegetation).
Potential use	There are a great variety of volcanic rocks and structures exposed in Giffard Bay. The site could be part of a Jersey geological trail, or geological information on the bay could be included in literature/leaflets describing the Jersey Coastal Path.

Site Photos:

Photo 1: General view looking east from La Crête Fort, taken from the Jersey Coast Path. BGS © UKRI 2020.

Photo 2: Layering within the Frémont Ignimbrite of the St John's Rhyolite Formation at the western end of Giffard Bay. BGS © UKRI 2020.

Photo 3: Agglomerate within the Frémont Ignimbrite of the St John's Rhyolite Formation at the western end of Giffard Bay. BGS © UKRI 2020.

Photo 4: Spherulites within the Giffard Rhyolite at the western end of Giffard Bay. BGS © UKRI 2020.

Photo 5: Flow folding in Giffard Rhyolite. BGS © UKRI 2020.

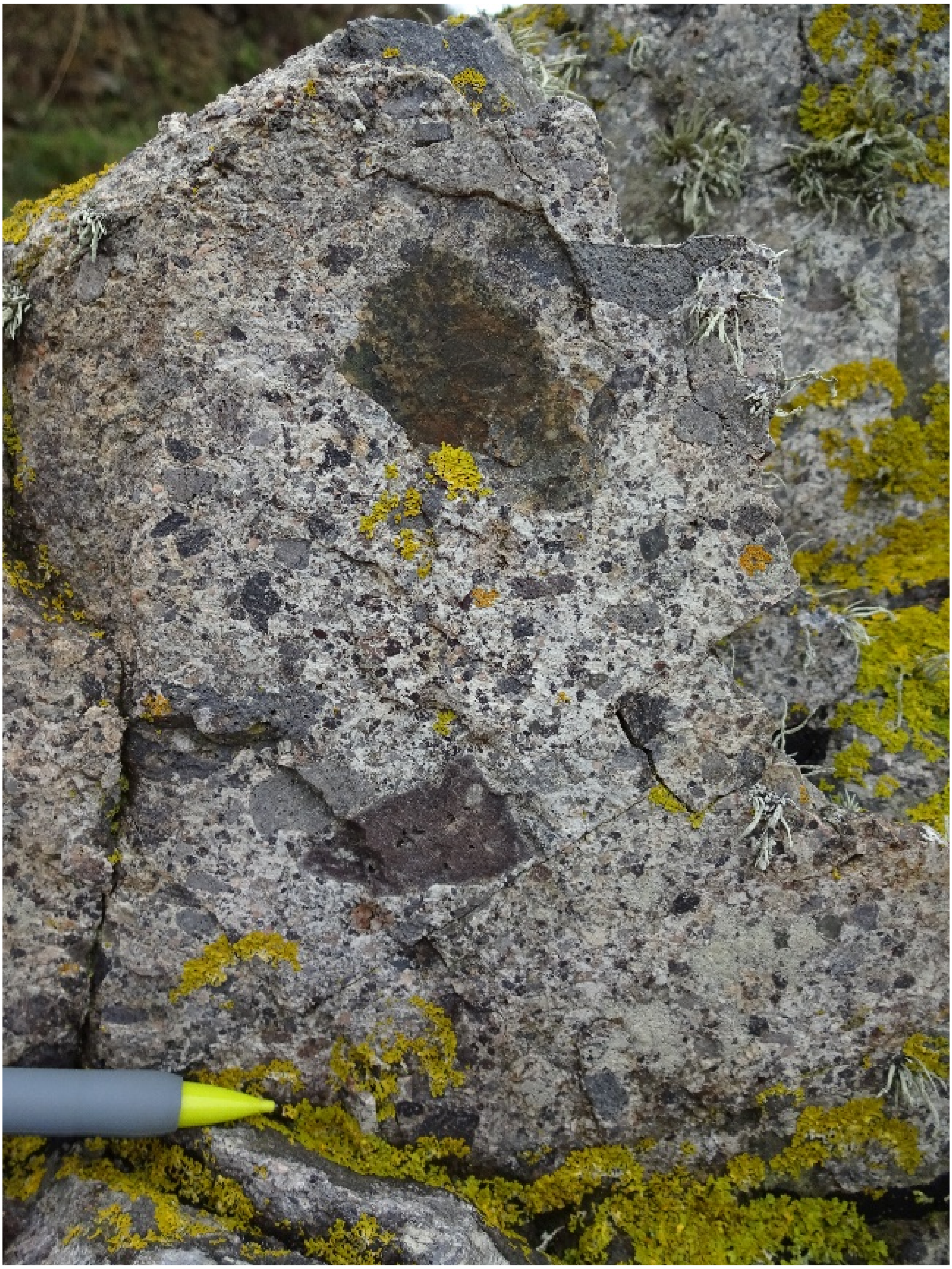


Photo 6: Giffard Andesitic Agglomerate. BGS © UKRI 2020.

Photo 7: Snowflake devitrification texture in rhyolite cobble from western end of beach. BGS © UKRI 2020.

Photo 8: Mica-lamprophyre dyke cutting foreshore outcrop of Giffard Rhyolite at the central part of Giffard Bay. BGS © UKRI 2020.

Photo 9: (BGS Ref: P005389). Water-lain tuffs in the Giffard Tuff. Green and purple water-lain tuffs, overlain by coarse agglomerate. GM Thomas, 1976. BGS © UKRI 2020.

Photo 10: Giffard water-lain tuff. BGS © UKRI 2020.

Photo 11: (BGS Ref: P005391) Lacustrine-deposited tuff in the Giffard Tuff. Graded colour-banded tuff that was deposited by air fall into a standing body of water. GM Thomas, 1976. BGS © UKRI 2020.

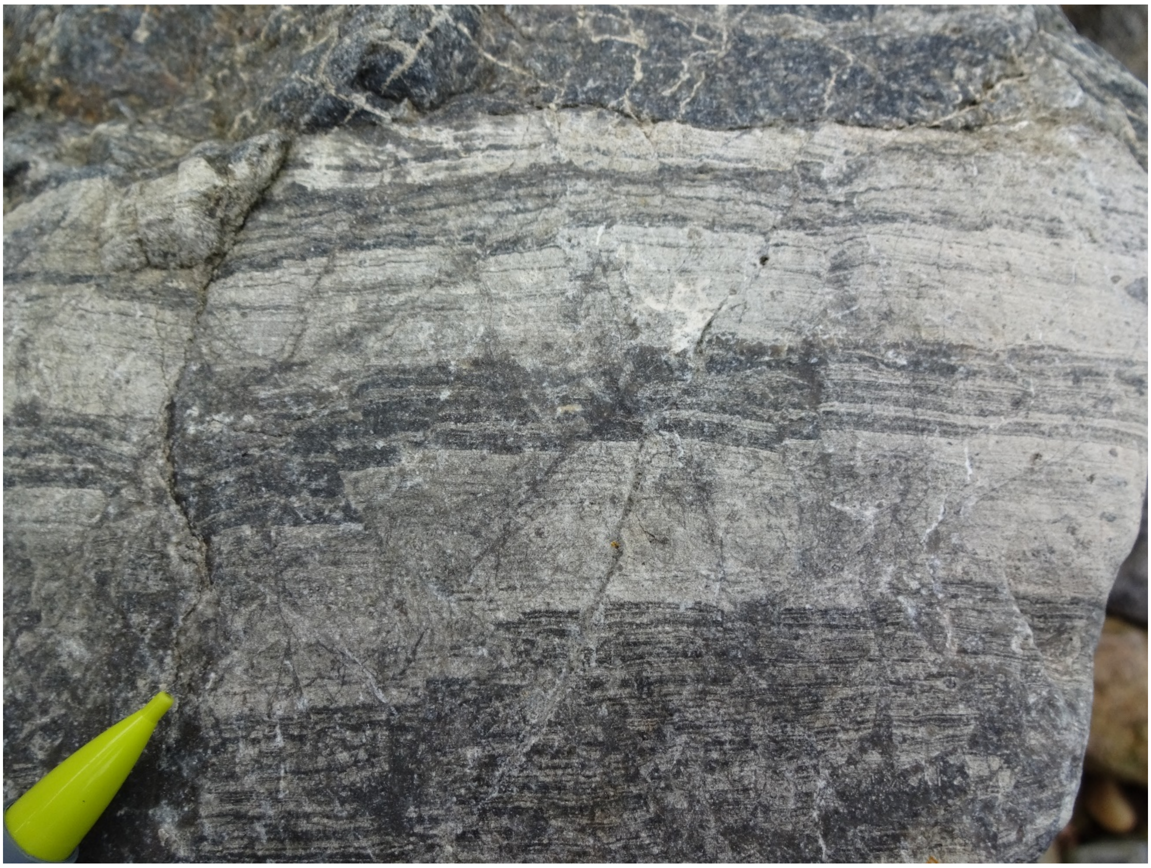


Photo 12: Boulder displaying small-scale faulting in lacustrine-deposited tuff. BGS © UKRI 2020.

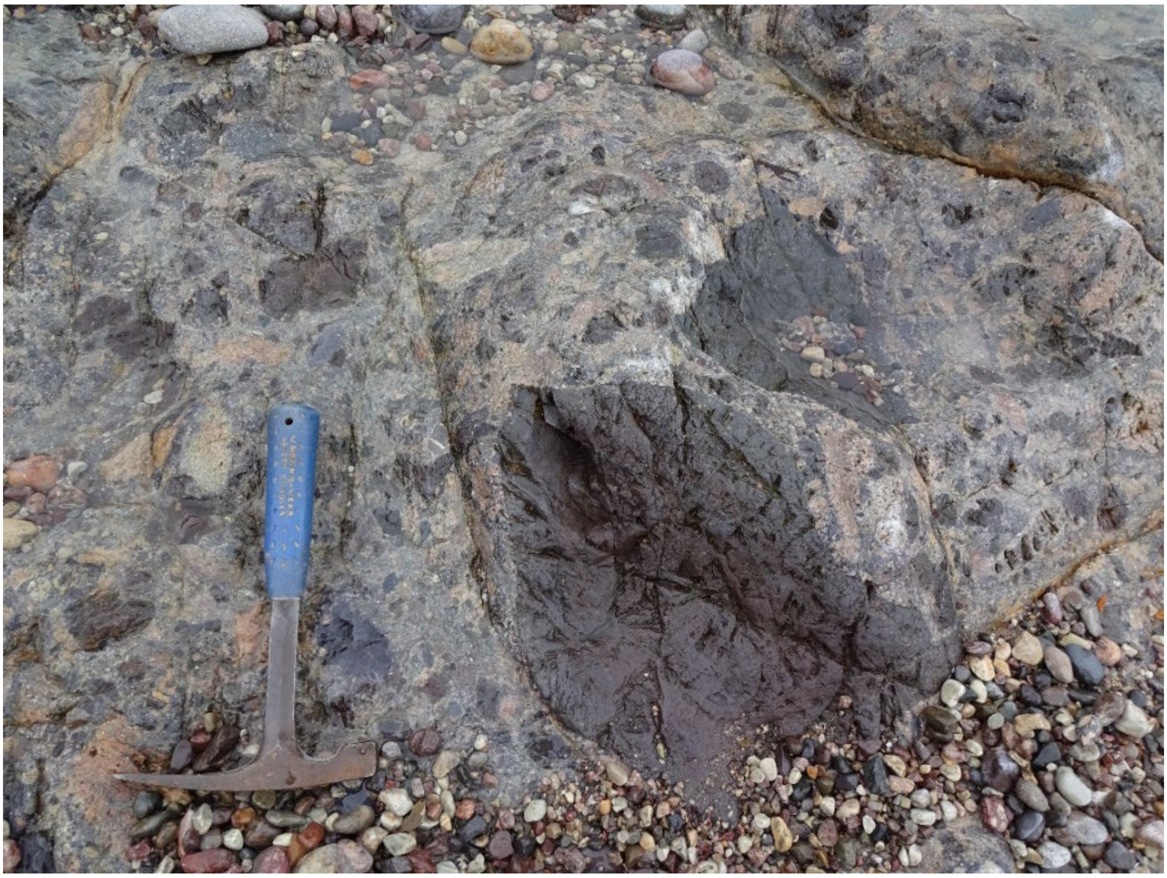


Photo 13: Agglomerate with blocks of andesite and rhyolite within the Giffard Tuff at the central part of Giffard Bay. BGS © UKRI 2020.

Photo 14: Jersey Shale graded beds and distal turbidites at the south-east corner of Giffard Bay. BGS © UKRI 2020.

Photo 15: Small-scale faulting and calcareous weathering of the *Jersey Shale Formation* at the south-east corner of Giffard Bay. BGS © UKRI 2020.

Photo 16: Grading in silty sandstone turbidites with thin channelled sandstone in the *Jersey Shale Formation* at the south-east corner of Giffard Bay. BGS © UKRI 2020.

Photo 17: (BGS Ref: P005384) L'Homme Mort Conglomerate. Polymictic conglomerate that is partly laharic in origin; it post-dates the Belle Hougue Andesite but pre-dates the rhyolites. Unlike the Rozel Conglomerate, this sediment is affected by the Frémont Fault. GM Thomas, 01/01/1976. BGS © UKRI 2020.

Photo 18: L'Homme Mort Conglomerate, deformed with mylonitic fabric on the foreshore cliff to the north of the Frémont Fault zone at the south-east corner of Giffard Bay. BGS © UKRI 2020.

Photo 19: L'Homme Mort Conglomerate, undeformed, on the foreshore cliff to the north of the Frémont Fault zone in the south-east corner of Giffard Bay. BGS © UKRI 2020.

Photo 20: (BGS Ref: P005420) Mylonite. Mylonitic shear zone (the Frémont Fault) containing fragments of shale, andesite and rhyolite in the fine-grained matrix. GM Thomas, 1976. BGS © UKRI 2020.

Photo 21: (BGS Ref: P005378) Vicard Tuff. Sharp undulatory base of the greenish grey Vicard Tuff, which overlies the basal breccio-conglomerate of the St Saviour's Andesite Formation. The base of the younger purple Belle Hougue Andesite is visible just to the left of the hammer. GM Thomas, 1976. BGS © UKRI 2020.

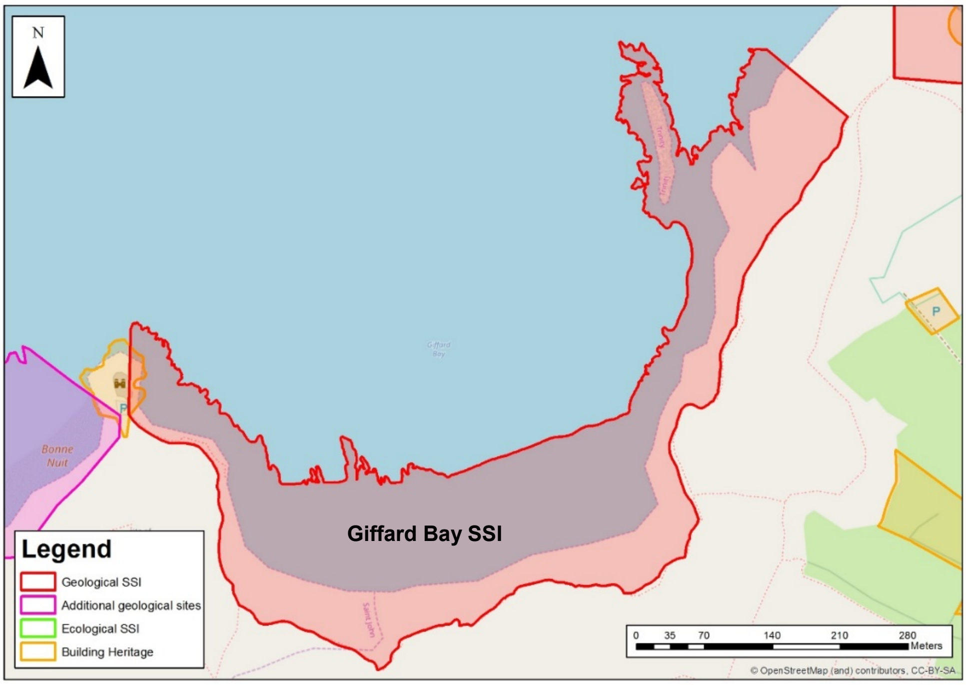
Photo 22: (BGS Ref: P005383) Graded sediments in breccio-conglomerate in the Belle Hougue Andesite. Graded grits and mudstones from the upper part of the breccio-conglomerate found at the base of the Belle Hougue Andesite. The grading indicates local overturning. GM Thomas, 1976. BGS © UKRI 2020.

Photo 23: Head overlying 8 m raised beach, central part of Giffard Bay. BGS © UKRI 2020.

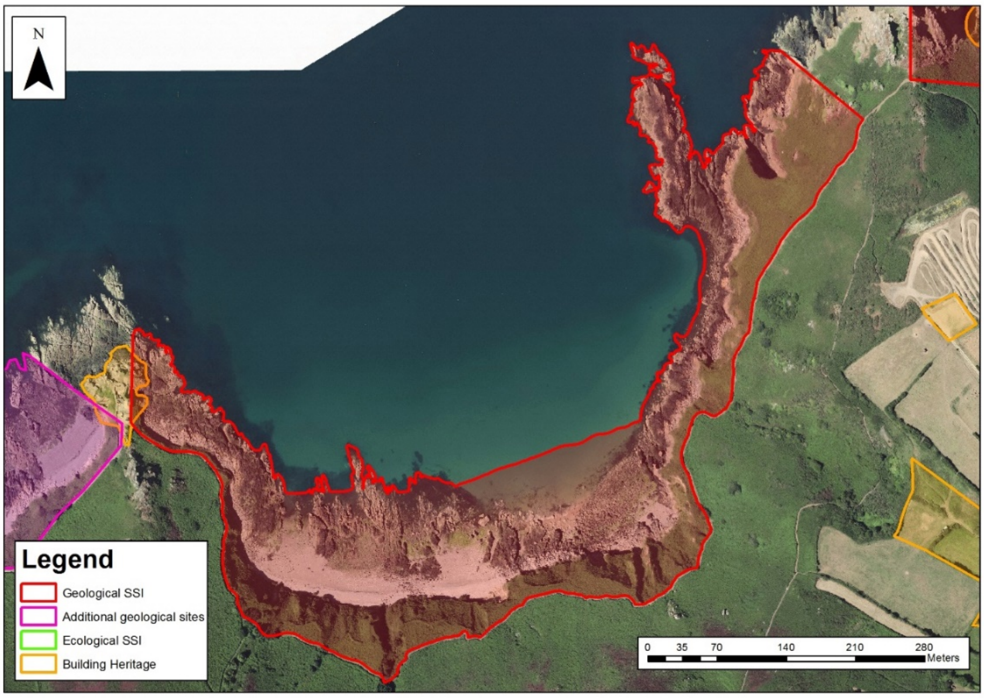
Photo 24: Close-up of 8 m raised beach, with pebbles of rhyolite and jasper pebbles, at the central part of Giffard Bay. BGS © UKRI 2020.

Photo 25: Thick bouldery head resting on Bouley Rhyolite Formation cliff in the central part of Giffard Bay. BGS © UKRI 2020.

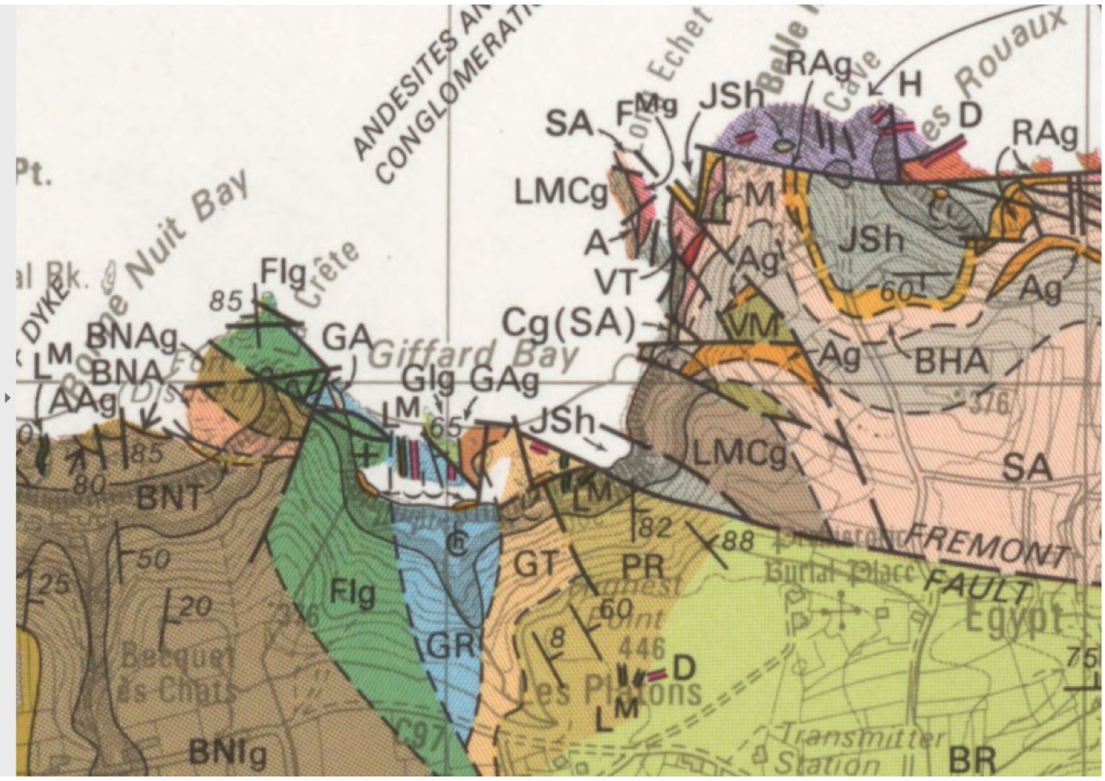
Map of the site boundary on a topographic base



Map of the site boundary on an aerial photograph

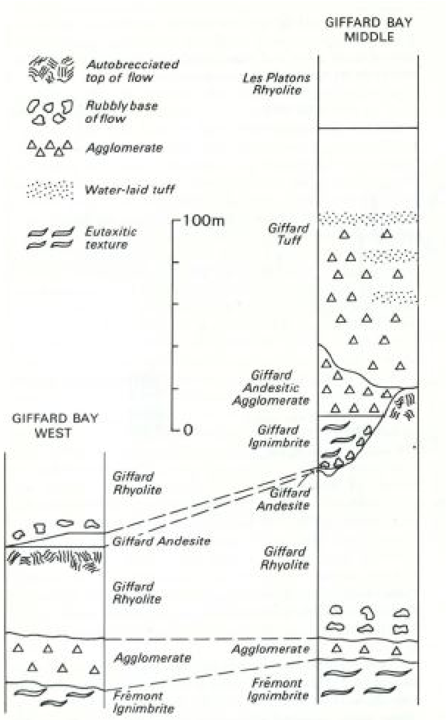


Published geological map of the site



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

Generalised vertical sections through the rocks of the Bouley Rhyolite Formation exposed in Giffard Bay (reproduced from Bishop and Bisson, 1989, figure 11). © BGS, NERC.

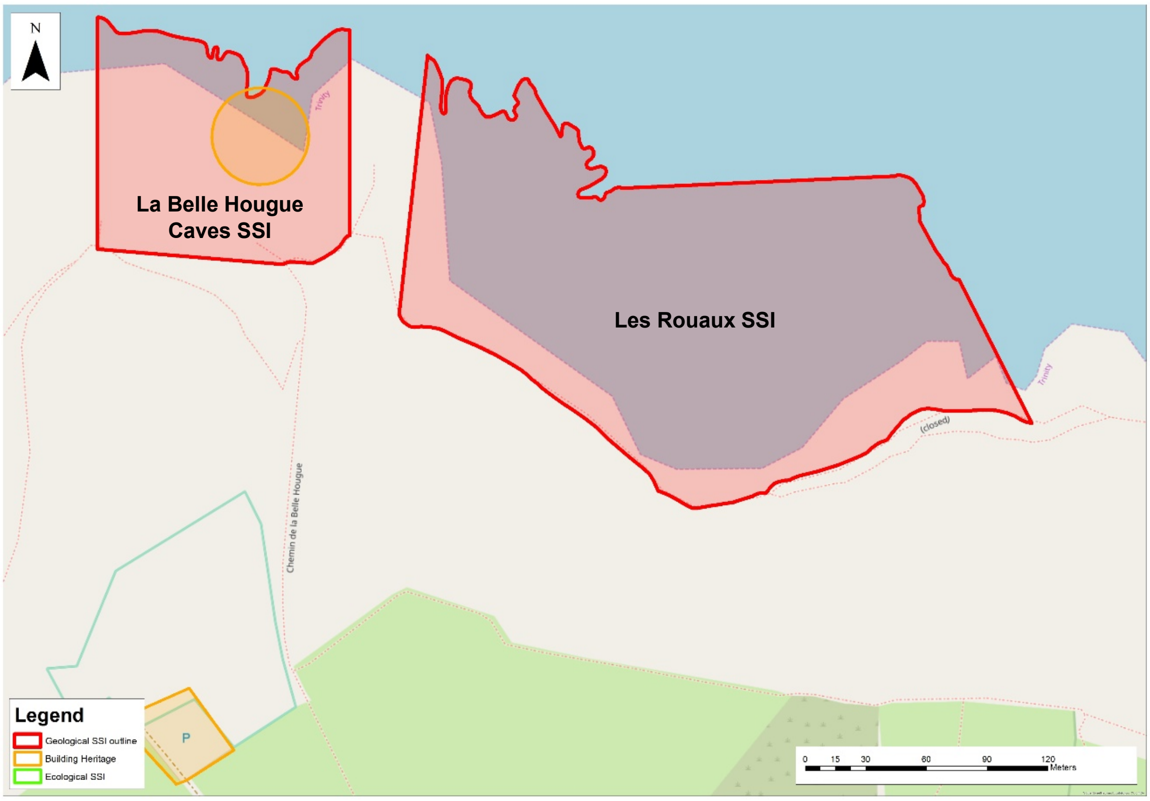


7.4 SITE NAME: LES ROUAUX, SSI

Site Information:
Les Rouaux is an existing SSI on Jersey's north coast, where a number of geological features are exposed on the 8 m wave-cut bedrock platform. The shore platform is very difficult and dangerous to access directly from the coastal path, but the viewpoint on the headland gives a panoramic view of Les Rouaux Fault. It shows that rocks of the Belle Hougue igneous complex are clearly faulted against the *Jersey Shale Formation* and the St Saviour's Andesite Formation. Sedimentary structures and deformation features have been recorded within the *Jersey Shale Formation*, which transitions upwards into the volcanic rocks of the St Saviour's Andesite Formation; this formation can be examined in exposures along the clifftop path.

National Grid Reference: Mid-point: 42775, 73241 West end: 42634, 73238 East end: 42946, 73184	**Site Type:** Natural section/exposure
Site Ownership: Private	**Current Use:** Open country, coastal
Field Surveyors: S Arkley and C Auton	**Current Geological Designations:** Geological SSI: Les Rouaux (Local A)
Date Visited: 17 October 2019	**Other Designations:** Within Jersey National Park

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Latest Precambrian (Ediacaran)	**Formation:** *Jersey Shale Formation*
Rock Types: Sandstone, siltstone and claystone with rare intra-formational conglomerates	
Age: Upper Cambrian to Ordovician	**Formation:** Belle Hougue igneous complex (a component of the *North-west igneous complex*)
Rock Types: Altered diorite and veined and brecciated granite	
Age: Latest Precambrian (Ediacaran)	**Formation:** St Saviour's Andesite Formation
Rock Types: Andesite, agglomerate, tuff, mudstone and conglomerate	
Age: Late Cambrian to Ordovician	**Formation:** Dykes
Rock Types: Dolerite	
Age: Quaternary	**Formation:** Head
Rock Types: Not seen but likely to comprise a poorly sorted and weakly-stratified deposit containing angular blocks of local bedrock	

Site Description:

Introduction

Les Rouaux is a small bay east of Belle Hougue Point where diorite and granite are juxtaposed against rocks of the *Jersey Shale Formation* and members of the St Saviour's Andesite Formation by the Les Rouaux Fault (Photos 1 and 2). The rocks are exposed on a shore platform at 8 m above mean sea level, where they are backed by steep vegetated cliffs formed of head. A well-developed 2 m wave-cut notch has been recognised at the onshore side of the platform. No access to the rocks on the shore platform was attempted at the time of the site visit, as no clear path was visible down the steep cliff. The detailed description of the geological features presented here is based upon the accounts of the site provided in Bishop *et al*. (1989, 2003). However, the most important larger-scale feature of the site, which is the surface expression of Les Rouaux Fault, can be clearly seen from Belle Hougue Point and from the lower coastal path that traverses eastwards along the landward side of the cliffs towards La Colombiére.

Bedrock Units

Les Rouaux Fault

The generally E–W-trending Les Rouaux Fault is mapped extending from just south of Belle Hougue Point to the vicinity of La Colombiére (both beyond the boundary of the Les Rouaux site). However, the structure is most clearly seen in the foreshore platform in Les Rouaux Bay (Photo 1), where it is marked by a narrow steep-sided gully separating granitic rocks, on its northern (seaward) side, from sedimentary rocks of the *Jersey Shale Formation* and andesitic pyroclastic rocks of the *St Saviour's Andesite Formation*. The fault is described by Bishop *et al*. (1989) as a vertical brittle structure that downthrows towards the south-east, but with an apparent dextral strike-slip component (displacement) of *c.* 300 m. Cataclastic fabrics (fabrics where the mineral grains have been broken up and comminuted in size as a result of brittle deformation) have been recorded from plutonic igneous rocks close to Les Rouaux Fault, indicating periods of significant and/or intense fault movement.

Jersey Shale Formation

Sedimentary rocks of the Ediacaran (late Precambrian) *Jersey Shale Formation* crop out on the landward, southern (downthrown) side of Les Rouaux Fault (Photos 1 and 7). They are best exposed on the foreshore platform, where they are described by Bishop *et al.* (2003) as displaying penecontemporaneous (synsedimentary) slumping and fracturing. The rocks are said to have a complicated pattern of folding with steeply plunging fold axes, which have been attributed to movement along Les Rouaux Fault. It is unclear, however, whether

Bishop *et al*. (2003) regard all of the folding and small-scale faulting as synsedimentary in origin.

St Saviour's Andesite Formation (Jersey Volcanic Group)

Volcanic rocks of the St Saviour's Andesite Formation, which comprises lavas, tuffs and agglomerates of andesitic and basaltic composition (Bishop and Bisson, 1989), are seen to overlie the Late Precambrian *Jersey Shale Formation* (at the eastern end of the shore platform). These volcanic rocks, the exposures of which extend onto the headlands at the eastern end of the Les Rouaux site, include the type-site of the Les Rouaux Agglomerate (Photo 4). Bishop *et al.* (1989) describe the Les Rouaux Agglomerate as being up to 25 m thick and containing angular fragments of the *Jersey Shale Formation*, andesite, porphyry and dark green pumice, within a purplish grey matrix. The pumice is confined to the lowest part of the unit and the matrix of the agglomerate has undergone felsic devitrification. The top of the Les Rouaux Agglomerate passes upwards into the overlying Vicard Tuff (Photo 3), which is recorded as being up to 80 m thick, and it is interlayered with the Belle Hougue Andesite. The Belle Hougue Andesite is up to 60 m thick at Les Rouaux but thins towards La Colombiére. The boundaries between the various volcanic units within the St Saviour's Andesite Formation at Les Rouaux are difficult to determine without detailed geological mapping, as most of the clifftop outcrops are covered in moss and lichen (Photo 5).

Age of the sequence south of Les Rouaux Fault

The youngest concordant detrital zircons from a sample of sandstone within the *Jersey Shale Formation*, dated by the U-Pb isotopic method, yielded ages of 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma (Miller *et al.,* 2001), giving an indication of a maximum age for the deposition of at least part of the *Jersey Shale Formation*. The *Jersey Shale Formation* is also mapped, in apparently un-faulted contact with agglomerate within the St Saviour's Andesite Formation, inland of the Les Rouaux site. If the deposition of parts of the *Jersey Shale Formation* took place about 587 Ma and the Bouley Rhyolite Formation (Anne Port Rhyolite) was erupted around 583 Ma, much of the *Jersey Volcanic Group* would have been formed between these dates. Bishop *et al.* (2003) note that the *Jersey Shale Formation* and the volcanic rocks were folded prior to the emplacement of the South-west granite *c.* 580 Ma (Miller *et al.*, 2001).

Belle Hougue igneous complex

Plutonic igneous rocks of the Belle Hougue igneous complex are exposed on the Belle Hougue headland and on the northern side of Les Rouaux rock platform. These rocks are faulted against the *Jersey Shale Formation* on the shore platform and against rocks of the St Saviour's Andesite Formation in the headlands at the eastern end of the site. The intrusive igneous rocks on the shore platform (Photos 6 and 7) are coarse-grained and principally of granitic, syenitic or dioritic composition depending upon the relative amounts of potassium feldspar, plagioclase feldspar and quartz, with the more dioritic rocks containing a higher proportion of mafic minerals. Bishop *et al.* (1989) stated that the diorites contain ragged crystals of green amphibole, altered plagioclase and abundant epidote and that most of the granitic rocks are adamellites. Some of the granitic rocks that are depleted in quartz are monzonitic; others that are rich in K-feldspar have a granophyric texture. Many have cataclastic fabrics related to later brittle deformation.

Diorite and gabbro, mapped as occurring below the granitic and syenitic rocks, underlie the Belle Hougue headland. At the western end of the rock platform, these more basic plutonic rocks are separated from the granites and syenites by a SW–NE-trending fault. A dolerite dyke, intruded along the fault plane, has been partly eroded away to form a narrow straight-sided gully (Photo 6), similar to the gully that marks the trace of Les Rouaux Fault. The diorite that crops out on the rock platform to the north of the fault contains inclusions of a coarse-grained pink granite forming veins and irregular pods (Photo 6). Similar lenticular inclusions of pink granite occur within the diorite exposed close to the entrance of the nearby Belle Hougue Cave site. These basic plutonic rocks are not included within the Belle Hougue igneous complex (see the key to the BGS 1: 25 000 scale geological map) and the published descriptions of these rocks are ambiguous about whether or not they constitute part of this complex. Nevertheless, the basic plutonic rocks are thought to be of a similar age to the more acid members of the complex and are probably related to it.

Age of the Belle Hougue igneous complex

A small outcrop of diorite and granite (the latter described as being ‘syenitic’ locally) at Belle Hougue Point has been referred to previously as the Belle Hougue igneous complex (IGS, 1982). The rocks here have not been dated directly, but close proximity to the eastern part of the *North-west igneous complex* and broad lithological similarities with the rocks there suggest that the *North-west igneous complex* and Belle Hougue igneous complex are related.

A U-Pb zircon age of *c.* 483 Ma for a sample of St Mary’s granite from Mont Huelin Quarry in the west of Jersey, within the outermost zone of the main crop of the *North-west igneous complex* (Miller *et al.,* 2001), confirms that it was emplaced in the Ordovician Period.

Quaternary Sediments

Head deposits are reportedly concealed beneath the dense vegetation covering the steep cliffs on the landward side of the bay. The nature of the head is unknown, as no detailed descriptions of exposures are available, and no exposures were visible at the time of the site visit.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	A car park is located approximately 275 m south-west of the site, near Belle Hougue viewpoint, off La Rue d’Egypte. The parking area is a reasonable size and lies adjacent to a dirt bike track. Note that the site is not visible from the car park.
Access to the site	The site is viewed/accessed from the Jersey Coastal Path, which is a short walk from the car park across the dirt bike track. The coastal path forms the southern site boundary and runs along the back of the bay (although at some height above the foreshore). Many of the key geological features at the site can be viewed from the coastal path. However, if a more detailed inspection of the rocks is required, access to the shore platform is possible, but great care should be taken as the route is unclear and the ground is very steep. Although the Geologists’ Association guide describes ‘a steep grassy cliff path’ descending down to the rocky platform at Les Rouaux, this path could not be found on the site visit and may now be overgrown. Access could be improved, but this may encourage unprepared visitors to venture onto difficult/exposed ground.
Safety of access	If the bike track is in use, great care should be taken when passing across it, or perhaps it should be avoided altogether. The Jersey Coast Path, although narrow in

	places, is in good condition and appears to be well maintained. The path down onto the wave-cut platform (if it still exists) is not easily identified and would go down the very steep vegetated cliff surrounding the bay. Great care should be taken if this descent is attempted; it could be treacherous when wet. All visitors should be aware of the tide times and access routes when planning a visit, as most of the bedrock exposures are in the intertidal zone and will be covered at high tide. Stout footwear is recommended for visitors intending to go off the coastal path.
Safety of exposure(s)	The shore platform is covered at high tide and surrounded by high vegetated cliffs, so knowledge of tide times is essential for any visit. The cliffs reportedly expose head deposits at the back of the bay; these deposits are probably quite stable, but they are high and made of largely unconsolidated material. Visitors would therefore be advised to wear hard hats if they wish to inspect the deposits up close. The intertidal bedrock exposures will likely have an uneven, water-worn surface and could be slippery with algae and seaweed – stout boots are recommended.
Current condition	From the coastal path, most of the bedrock exposures on the shore platform appear to be clean and free of vegetation. However, being in the intertidal zone, it is expected that some of the rocks will be covered by barnacles, algae and seaweed. Inland exposures are well spread and largely covered in moss and lichen. The condition of the sections exposing the head deposits is unknown.
Current conflicting activities	None are known at the site itself. If the dirt bike track is in use, an alternative route may need to be found to get from the car park to the coastal path.
Restricting conditions	Tide: much of the exposure is within the intertidal zone and therefore covered at high tide.
Nature of exposure(s)	Intertidal bedrock outcrops with some high largely vegetated cliffs

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Near a listed place (TR0086): Belle Hougue Caves (HER Number 1200086), where two sea caves discovered between 1913 and 1919. Near La Fontaines des Mittes (HER Number 1200271), where there is a local legend about a spring (Jersey Folklore site). Neolithic flint flake tool found nearby at

	Belle Hougue Point (Date: 35,000–25,000 BC; Length: 5.73 cm, Width: 4.16 cm, Thickness: 0.86 cm; Donated by S. Le Goubin).
Aesthetic landscape	Coastal – a small bay on the Belle Hougue Headland. The headland stands proud due to the resistant nature of the rocks from which it is composed. There are impressive views northwards across to Guernsey, Sark and the French coast on a clear day from the headlands on either side of the bay and the Jersey Coastal Path.
History of Earth science	No known associations
Economic geology	No known associations

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	National	Good	Detailed	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The Les Rouaux site provides the best exposure of a faulted (tectonic) contact between rocks of the Belle Hougue igneous complex, which are clearly faulted against the *Jersey Shale Formation* and the St Saviour's Andesite Formation, all of which are exposed on the 8 m wave-cut bedrock platform. The shore platform is very difficult and dangerous to access directly from the coastal path, but the viewpoint on the headland gives a panoramic view of Les Rouaux Fault. The volcanic rocks of the St Saviour's Andesite Formation can be examined in exposures along the clifftop path.

Assessment of Site: Current Site Usage

Community	The Jersey Coastal Path, which runs along the edge of the bay (although at some height above the beach), is frequently used by locals and tourists; however, few people are thought to go down onto the foreshore. There is no café and no toilets at the site.
Education	The geoscientific value of Les Rouaux is considerable. There is a variety of plutonic, volcanic and sedimentary lithologies that can be examined here, as well as a number of geological structures. Although the relationships between some of the units are complex, others can be observed from a distance and clearly pointed out to younger or less knowledgeable visitors; the relative ages of these units can then be discussed. The opportunity to study the relationships between the units will be of great interest for higher education and research groups.

	The site also displays some good examples of coastal geomorphology and highlights how the landscape often reflects the underlying geology through the erosion/weathering of softer or more fractured strata.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Like all coastal locations, the site is subject to high-energy weathering and erosion. However, the bedrock exposures are fairly robust. The base of the cliff sections at the back of the bay is likely subject to some washing and minor erosion by storm waves, but this will help to keep any sections through the Quaternary deposits exposed (free of vegetation).
Potential use	There is a good variety of lithologies at Les Rouaux, along with some large-scale geological structures and coastal landforms. The site could be part of a Jersey geological trail, or geological information on the bay could be included in literature/leaflets describing the Jersey Coastal Path.

Site Photos:

Photo 1: View looking eastwards onto the 8 m wave-cut platform at Les Rouaux. The Jersey Coastal Path can be seen along the clifftop. The position of Les Rouaux Fault and a dolerite dyke can be seen (eroded out). The fault forms a narrow gully, trending west to east, towards the distant headland. The dolerite dyke, which is emplaced along a more minor fault, forms the wider gully in the foreground. Rocks of the *Jersey Shale Formation* are exposed on the landward (right-hand) side of Les Rouaux Fault. Granitic rocks of the Belle Hougue igneous complex crop out between Les Rouaux Fault and the dolerite dyke. Diorite with pods of pink granite occurs in the left foreground. BGS © UKRI 2020.

Photo 2: View from the coastal path looking westwards across the 8 m platform at Les Rouaux. The access path from the car park (part of the Jersey Coastal Path) can be seen zigzagging down the side of the Belle Hougue headland in the background. BGS © UKRI 2020.

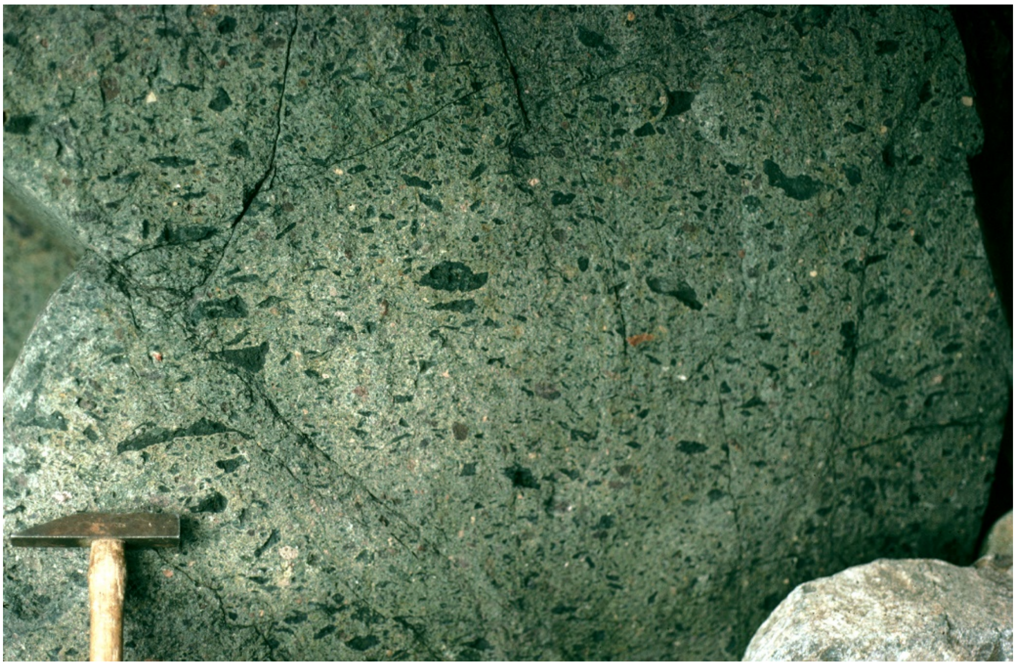


Photo 3: A patch of greenish Vicard Tuff (just to the right of the hammer) caught up in the purplish Belle Hougue Andesite, which forms one of principal volcanic rock units within the St Saviour's Andesite Formation in the cliff exposures at Les Rouaux. GM Thomas, 01/01/1976. BGS © UKRI 2020.

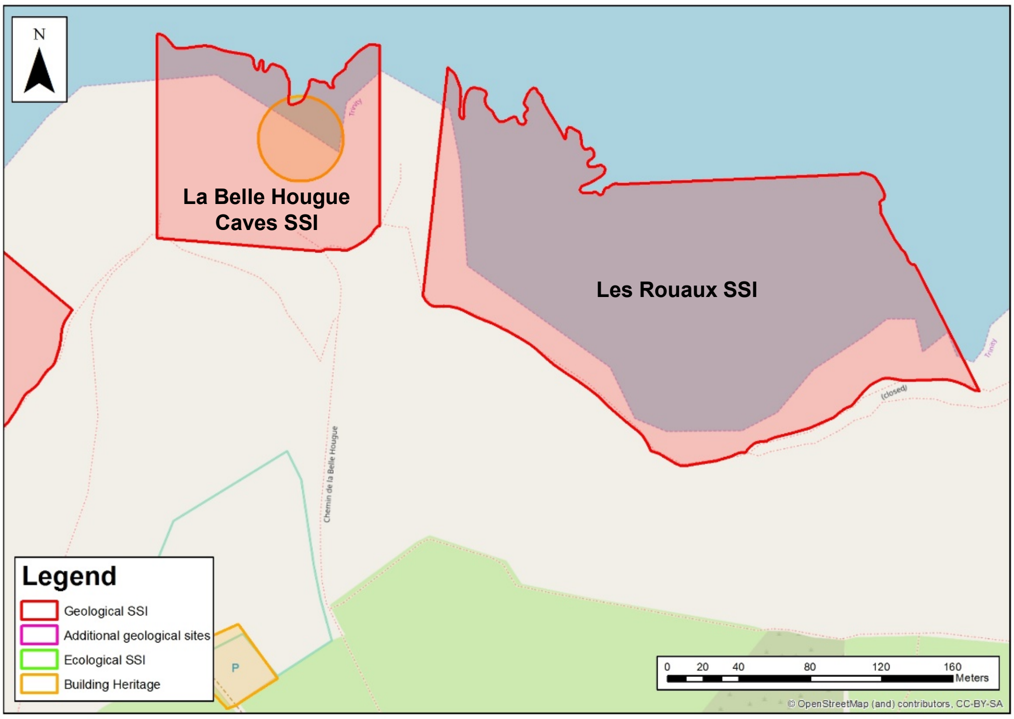
Photo 4: Les Rouaux Agglomerate occurs near the base of the Lower Palaeozoic St Saviour's Andesite Formation. It contains numerous green pumice fragments, with subordinate fragments of shale, andesite and rhyolite, showing a crude layering that parallels 'bedding'. (BGS Ref: P005377) GM Thomas, 01/01/1976. BGS © UKRI 2020.

Photo 5: View from the eastern end of the Les Rouaux site, displaying a typical moss-and-lichen-covered clifftop exposure of volcanic rocks within the St Saviour's Andesite Formation. BGS © UKRI 2020.

Photo 6: Pale-coloured (orange-pink) granitic rock occurs as a pod within the dioritic and gabbroic plutonic rocks exposed at the western end of the 8 m wave-cut platform. A dolerite dyke (eroded gulley) cuts through the igneous rocks and separates the basic (dioritic and gabbroic) rocks (left side of image) from the acid (granitic and syenitic) plutonic rocks (right side of image). BGS © UKRI 2020.

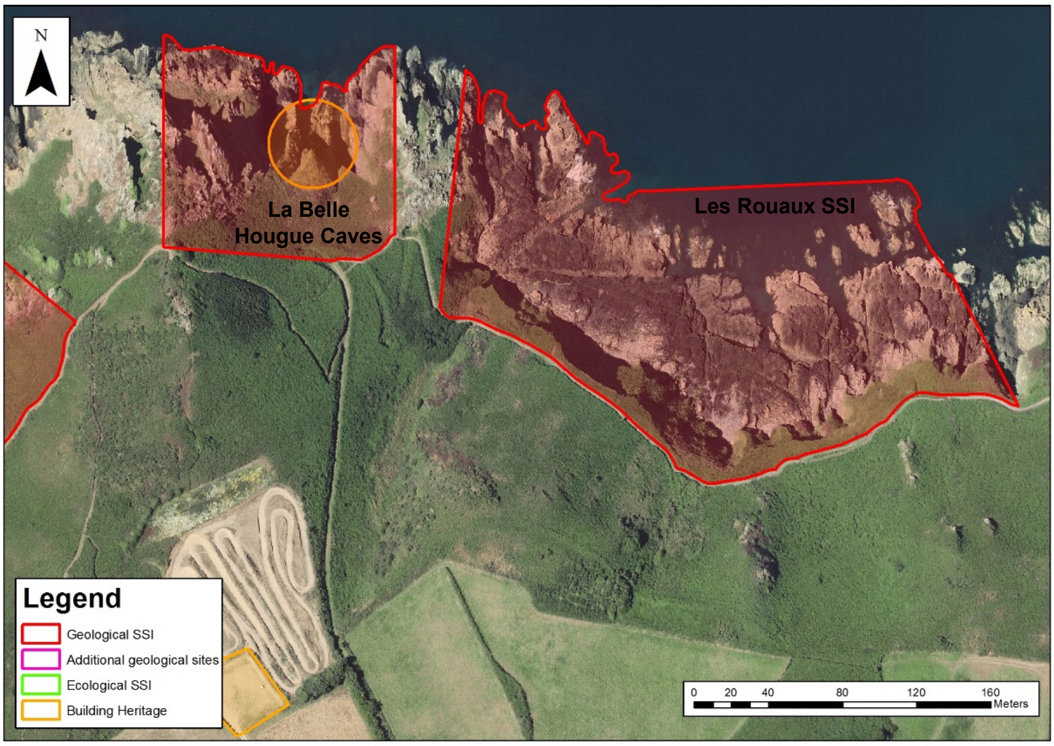
Photo 7: View across the 8 m wave-cut platform looking west. The dark grey rocks (foreground) that lie south of the fault belong to the Brioverian *Jersey Shale Formation*, and the igneous rocks north of the fault belong to the Belle Hougue igneous complex. BGS © UKRI 2020.

Map of the site boundary on a topographic base



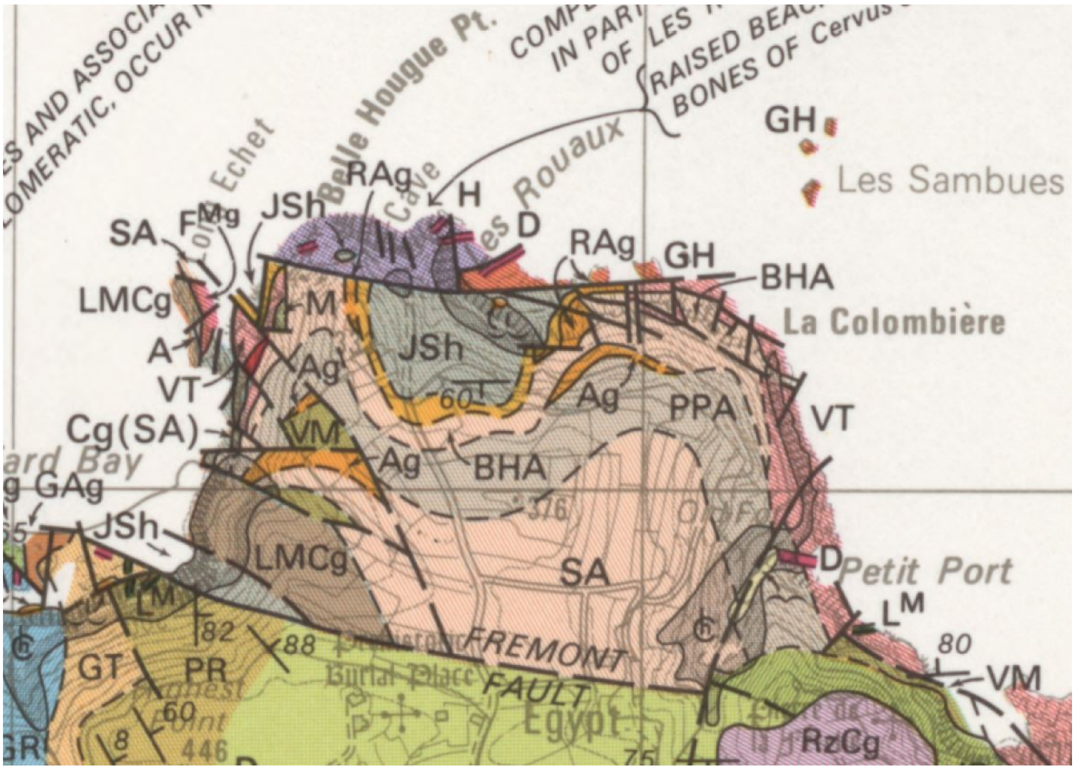
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



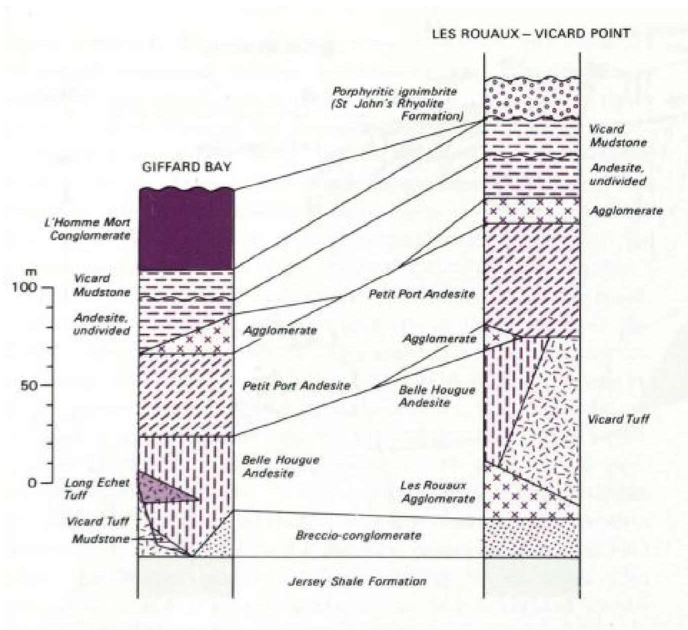
Imagery ©2020 Government of Jersey.

Published geological map of the site



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

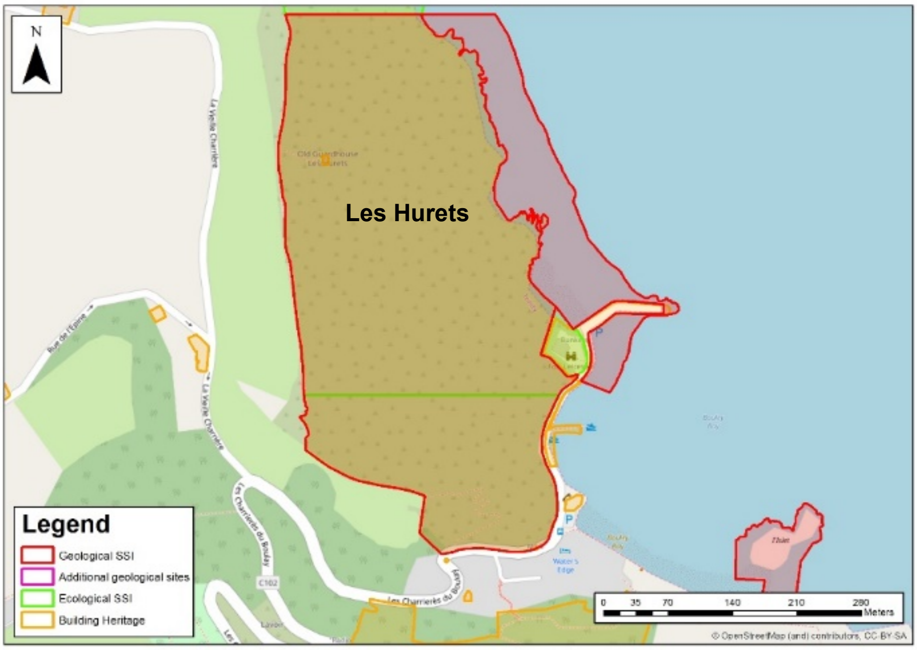
Correlation of the rocks of the Jersey Volcanic Group exposed on the headland on the north-east side of Giffard Bay and those exposed between Les Rouaux and Vicard Point; reproduced from Bishop and Bisson (1989, figure 4). © BGS, NERC.



7.5 SITE NAME: LES HURETS, BOULEY BAY, SSI

Site Information: Les Hurets, Bouley Bay, is an existing SSI on Jersey's north coast containing ignimbrites and rhyolites of the Bouley Rhyolite Formation. Large fallen blocks on the foreshore at the western end of Bouley Bay contain impressive examples of spherulites showing a range of sizes and forms; they can be seen *in situ* in small exposures on the path to Les Hurets Old Guardhouse and around the guardhouse itself. The 8 m raised beach, resting on gravel head and overlain by bouldery head, can be seen at the back of the bay.	
National Grid Reference: Mid-point: 43737, 71777 North end: 43696, 72067 South end: 43745, 71481	**Site Type:** Natural section/exposure
Site Ownership: Private	**Current Use:** Open country, coastal
Field Surveyors: S Arkley, C Auton, R Kendall, J Everest, L Hughes and M Gillespie	**Current Geological Designations:** Geological SSI
Date Visited: 22 September, 13 October, 15 October and 18 October 2019	**Other Designations:** Ecological SSI: Fort Leicester and Bouley Bay & Les Hurets. Building Heritage: Les Hurets Guardhouse (TR0201) lies within the site. Fort Leicester (TR0117), Bouley Bay Harbour (TR0116), German occupation site: Casemate, R.N. Bouley Hafen (TR0123), Milestone '5' (TR0120) and German Occupation site: Inscribed bricks (TR0122) lie adjacent to the boundary. Other: Areas above the HWM are within Jersey National Park.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** Bouley Rhyolite Formation
Rock Types: Complex assemblage of extrusive igneous rocks principally comprising rhyolites, andesites, tuffs, ignimbrites and agglomerates	
Age: Quaternary	**Formation:** Head
Rock Types: Poorly sorted deposit containing angular and tabular blocks of local bedrock in a sandy/gritty matrix	
Age: Quaternary	**Formation:** Raised beach
Rock Types: Rounded pebbles and gravel	

Site Description:

Introduction

Les Hurets, Bouley Bay, is an existing SSI on Jersey's north coast containing ignimbrites, rhyolites and tuffs of the Bouley Rhyolite Formation. This is a large site that includes rock exposures on the foreshore, large inaccessible cliffs inland of the beach, crags to the south of Les Hurets Old Guardhouse and small exposures around the guardhouse itself. Large fallen blocks of rock and water-worn cobbles on the foreshore at the western end of Bouley Bay contain impressive examples of spherulites showing a range of sizes and forms; they can also be seen *in situ* in small exposures on the path to the guardhouse. The 8 m raised beach overlain by bouldery head can be seen at the back of the bay.

The International SSI designation of the site is mainly because of the impressive spherulites developed within the acidic volcanic rocks, particularly the ignimbrites. The rhyolites were deposited as high-temperature pyroclastic flows, which have been welded by subsequent compaction, and they were also erupted as high-temperature glassy lava flows. These rocks show flow banding and flow folding because of deformation caused by inhomogeneities within the rhyolite during viscous flow. Such natural glasses are unstable and start to hydrate and crystallise, or devitrify, soon after they have formed. The rocks are now preserved as partially devitrified hydrated glasses in which crystallisation resulted in the spontaneous growth of tiny crystals (microlites) of quartz and/or feldspar. These crystallites formed the nuclei upon which continued devitrification caused the growth of spherulites. These devitrification structures are formed of radiating clusters of crystals, which form small spherical structures resembling cod roe or bunches of grapes. The rocks at Les Hurets, Bouley Bay, contain spectacular examples of spherulite growth, with individual spherules reportedly reaching up to 10 cm in diameter (Mourant, 1932). Most of the rocks are only partially devitrified, as complete devitrification leads to the development of aphyric microcrystalline rock in which most evidence of flow banding has been destroyed (overprinted) by recrystallisation.

Bedrock Units

Bouley Rhyolite Formation (Jersey Volcanic Group)

The Les Hurets, Bouley Bay site is the type area for the Bouley Rhyolite Formation. It displays a complex assemblage of extrusive igneous rocks principally comprising rhyolitic lavas, tuffs, ignimbrites and agglomerates, and andesitic lavas. Although fewer individual lithological units have been mapped at this site, the rocks are similar in many aspects to those exposed at the Giffard Bay site. However, flow-banded rhyolites and partly devitrified (spherulitic) rhyolites and rhyolitic ignimbrites form a much larger proportion of the volcanic succession in the type area of Les Hurets, Bouley Bay. Distinguishing between rhyolitic lavas and ignimbrites is often difficult at the outcrop level because of the degree of devitrification that the rocks have experienced.
Two main ignimbrite units have been recognised by Bishop and Bisson (1989):

The Vicard Point Ignimbrite occurs in the north-west part of the site. It is approximately 25 m thick and has an autobrecciated top and several rubbly layers.

The Bouley Bay Ignimbrite, which is generally pale green in colour (Photos 14 and 15), is divided into Lower, Middle and Upper units. The Lower Bouley Bay Ignimbrite (Photo 17) is approximately 80 m thick and overlies the Vicard Point Ignimbrite. The Middle Bouley Bay Ignimbrite is typically reddish-purple in colour and often has the appearance of a flow-banded rhyolite (Photo 12). Eutaxitic textures, more typical of a welded rhyolite ignimbrite (Photo 16), are also seen in some exposures. The Upper Bouley Ignimbrite is typically salmon pink in colour and up to 200 m thick. It consists of two flows. The upper flow has a brecciated top and base and displays a pronounced eutaxitic texture, with fiamme up to 30 mm in length. Pumiceous textures are also present. This unit is mainly mapped to the east of the adjacent L'Islet site.

A tuff unit, the Les Hurets Tuff, which is 35 m thick, is recognised by Bishop and Bisson (1989) only on the western side of the site. However, this tuffaceous rock is generally only clearly distinguished from the other volcanic units through detailed petrological study. A tuff of this type (Photo 5) is present on the hilltop, south of the Old Guardhouse.

The best exposures of spherulitic rhyolite and ignimbrite are reported by Mourant (1932, 1933c) within the steep, rocky cliffs of Les Hurets, which form the back of the middle part of the bay (Photo 1). These cliffs are inaccessible from the beach and cannot be reached from any coastal pathway. The cliffs are surrounded by very dense vegetation and were regarded as too hazardous to visit during this study.

The best *in situ* examples of spherulites occur at the top of the coastal ridge near Les Hurets Old Guardhouse (Photo 2), near the western margin of the site. Here, spherulites typically up to 1.5 cm in diameter can be seen in cross-section (Photo 3) within rhyolitic ignimbrite that also shows folded flow banding in adjacent exposures (Photo 4). Good examples of spherulites developed within flow-banded rhyolite and ignimbrite are also seen in small exposures (Photos 6 and 7) on the coastal path from Les Charrierés du Bouley (C102) to the Old Guardhouse. Other examples occur within the crags to the north of Les Charrierés du Bouley, and they have been described by Nichols and Blampied (2016, p. 46). These crags (Photos 8 and 9) can be accessed, with great difficulty, by scrambling through thick vegetation from the track on the northern side of the valley that runs parallel to the C102 as it descends towards the harbour. Rhyolite with flow banding and rhyolite with flow folding are the dominant lithologies within these exposures, but isolated spherulites and groups of spherulites (resembling bunches of grapes, Photo 11) can also be seen.

The most spectacular spherulites can be observed in loose blocks of rock, and in wave-polished cobbles on the foreshore, where examples resembling bags of marbles or peas can be seen on weathered rock surfaces (Photo 13). Good examples, seen in cross-section (Photos 14 and 15), show that the spherulites are built up of concentric shells of radiating acicular feldspar, formed during successive stages of growth and separated by quartz. Lees and Roach (1993) suggest that some of the rhyolites within the Bouley Rhyolite Formation were originally lava flows of the volcanic glass obsidian, and that perlitic textures associated with early spherulite growth, as well as snowflake textures, may support the accumulation of at least part of the sequence in a subaqueous setting.

Dating the Bouley Bay Ignimbrite sequence at Les Hurets, Bouley Bay

The U-Pb date of 583 ± 3 Ma (Miller *et al.*, 2001) obtained from zircons from the 130-m-thick flow-banded rhyolite with columnar jointing within the Bouley Rhyolite Formation at the Anne Port Bay site (Flow 5 of Bishop and Bisson, 1989) provides a potential maximum age for the Bouley Rhyolite Formation. The dated lava flow occurs at or near the top of the volcanic sequence within the Bouley Rhyolite Formation at the Anne Port Bay site, but it is regarded as occurring close to the base of the formation as a whole. There have been no detailed correlations between the sequences at Anne Port and Les Hurets, Bouley Bay, but regional mapping suggests that the ignimbrite-dominated sequence at Les Hurets, Bouley Bay, occurs higher in the Bouley Rhyolite Formation than the dated lava flow at Anne Port Bay, and it is therefore likely to have formed slightly later than 583 ± 3 Ma.

Quaternary Sediments

Small exposures of raised beach gravel resting on gravelly head are present directly beneath >12 m of boulder-scale head. These deposits are exposed in a cliff above the high-water mark at the back of the middle part of the bay (Photo 19). The raised beach deposits comprise an upper unit, *c.* 50 cm thick, of clast-supported, well-rounded pebble gravel. This overlies a middle unit of boulder and cobble gravel, up to 0.8 m thick, with well-rounded cobbles typically between 5 and 25 cm in diameter and sub-rounded boulders up to 60 cm in diameter. The cobbles show weakly developed imbrication. The basal unit deposit is generally well-sorted, rounded pebble gravel with moderate clast imbrication in a gritty matrix (Photo 22). The clasts include maroon and grey rhyolitic ignimbrite, andesite and other fine-grained volcanic rocks. The raised beach deposits are assigned to the 8 m raised beach. They pass directly down, with a gradational contact, onto a fine angular gravel head (Photos 20 and 21) with a matrix of coarse silty sand. The matrix of the gravel is partly cemented and more resistant to erosion than the overlying raised beach gravels. The weakly cemented angular gravel is interpreted as an early head deposit, formed prior to the accumulation of the 8 m raised beach. Similar indurated (compacted and hardened) angular gravel is exposed periodically beneath the sandy beach between the jetty at Bouley Bay Harbour and the adjacent Les Hurets, Bouley Bay site.

The bouldery head deposit that overlies the raised beach deposits contains angular blocks of local bedrock, some of which exceed 50 cm in diameter. The boulder head is very poorly sorted and displays the weakly developed stratification that is typical of head deposits elsewhere in Jersey.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Many off-road and roadside parking areas are located down by the pier and by the former hotel in Bouley Bay at the southern end of the site. Parts of the site can be viewed from the road down to Bouley Bay and from several places along the Jersey Coastal Path.
Access to the site	Access to foreshore exposures and Quaternary sections is over the pier wall and along the beach. Access to the hillside outcrops is via the Jersey Coastal Path. Many of the hillside/hilltop exposures are only accessible where the dense, high vegetation (mainly bracken and gorse) that covers much of Les Hurets has been cleared, though this protects some of the more vulnerable areas containing *in situ* spherulites from collectors.
Safety of access	There is safe access to the foreshore. However, all visitors should be aware of the tide times and access routes when planning a visit. Access to the southern outcrops is through high (mostly above head height) bracken and gorse bushes – gloves and protection over the arms and legs are recommended. Access to the exposures by the old guard house is via a well-maintained path. The field surveyors for this site never managed to reach the cliffs above the beach.
Safety of exposure(s)	The cliffs exposing the Quaternary deposits at the back of the beach appear to be generally stable, but care should always be taken beneath cliffs, particularly in any overhanging areas. The bedrock exposures on the foreshore have an uneven, water-worn surface and are often slippery with algae and seaweed. The southern outcrops are difficult to explore in places due to

	the steep and dense vegetation. Vegetation around the old guardhouse has recently been cut, and this made a number of small exposures very accessible from the Jersey Coastal Path.
Current condition	Although many of the hillside exposures are clean, they are surrounded by thick vegetation. Exposures within the intertidal zone are covered by barnacles, lichen, algae and seaweed in places. Areas of the cliff section at the back of the cliff are well exposed, while others are covered by vegetation.
Current conflicting activities	None known
Restricting conditions	Foreshore exposures and sections may not be accessible at high tide. Dense vegetation restricts access to hillside exposures. A steep climb is necessary to reach many of the hillside exposures, although the Jersey Coastal Path is well maintained.
Nature of exposure(s)	Intertidal bedrock exposures, Quaternary cliff sections and hillside/cliff bedrock exposures

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Jersey Place Names identifies the site of the Water's Edge Hotel as the location of a guard house and barracks; 1795 Richmond Map shows the likely building by the stream (HER Number 1200245). 19th-century Milestone '5' is along the border of the SSI (HER Number 1200120; Listed building TR0120). Nearby on Bouley Bay Hill are the inscribed bricks dating from the German Occupation (HER Number 1200122; Listed building TR0122). The SSI is near the site of Le Binaud (HER Number 1200151). Les Hurets Guardhouse, situated on the top of the headland north of Bouley Bay, is a rare surviving example of an 18th-century guardhouse (from *c.* 1780; HER Number 1200201; Listed building TR0201).
Aesthetic landscape	Located at the western end of a beautiful coastal bay in the north of Jersey, Bouley Bay has a small harbour and stony beach. There are panoramic views from the top of Les Hurets. No litter was seen.
History of Earth science	No known association
Economic geology	No known association

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Regional	Good	Detailed	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

Les Hurets, Bouley Bay, is an existing SSI on Jersey's north coast containing rhyolite flows and ignimbrites of the Bouley Rhyolite Formation. It is the best site for examining the spherulitic devitrification textures developed within the rhyolitic ignimbrites, tuffs and lavas in Jersey. However, the best examples are reportedly from the cliffs forming the bay, which are

very difficult to access due to dense and thorny vegetation. Nevertheless, large fallen wave-polished blocks on the foreshore at the western end of Bouley Bay contain impressive examples of spherulites showing a range of sizes and forms; they can also be seen *in situ* in small exposures on the path to Les Hurets Old Guardhouse and around the guardhouse itself. The 8 m raised beach, resting on gravel head and overlain by bouldery head, can be seen at the back of the bay.

Assessment of Site: Current Site Usage	
Community	The bay is popular with swimmers, kayakers and scuba divers (Bouley Bay Dive Centre). Locals and tourists are frequently seen on the Jersey Coastal Path. There is a café and toilets in Bouley Bay.
Education	The site displays a variety of volcanic rocks and textures, including spectacular examples of spherulites; the best examples are visible in water-worn fallen blocks and pebbles on the beach. Accessible cliff sections at the back of the beach display good examples of head and raised beach deposits. The bay is frequented by many people, and a geological interpretation board situated next to existing historical boards would likely be well read and might encourage visitors to explore less accessible parts of the area. The site (along with L'Islet, Geological SSI) could easily be part of a geological trail, as it is already a popular place for visitors interested in the outdoors. Access to the hillside/crag outcrops would need to be improved if they were to be used for educational purposes.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Like any coastal site, the intertidal areas are subject to high-energy weathering and erosion, but this also helps to keep exposures clear of vegetation and display geological features clearly. The cliff sections through the Quaternary deposits are above the normal high-tide mark. The bedrock exposures on Les Hurets where the spherulites are found *in situ* are vulnerable to collectors, but the existing high vegetation around many of the outcrops will deter all but the most determined collectors.
Potential use	This site has spectacular examples of spherulites and has the potential for further scientific work and to inspire those new to the subject. It could be included in geological guides, have an interpretation panel or be incorporated into a geotrail.

Site Photos:

Photo 1: View across Bouley Bay looking north-west to Les Hurets. The pier and Fort Leicester can be seen just left of the centre. The inaccessible cliffs where the best spherulites can be examined are just below the skyline in the middle background. The section in head overlying deposits of the 8 m raised beach can be seen to the right of the pier. BGS © UKRI 2020.

Photo 2: General view at the top of Les Hurets ridge, showing some typical exposures in the Bouley Rhyolite Formation and the Old Guardhouse. BGS © UKRI 2020.

Photo 3: Spherulites in cross-section, from the Middle Bouley Ignimbrite, on the hilltop at Les Hurets. The spherulites show the typical concentric growth of radiating fibrous feldspar from nucleated crystallites that have partly weathered away. BGS © UKRI 2020.

Photo 4: Possible flow banding within the Bouley Rhyolite Formation (probably Middle Bouley Bay Ignimbrite) on Les Hurets hilltop. BGS © UKRI 2020.

Photo 5: Pale tuff, possibly Les Hurets Tuff, on the hilltop, south of the Old Guardhouse. Note the angular and cuspate forms of the lapilli in the middle of the unit. BGS © UKRI 2020.

Photo 6: Possible flow banding in Bouley Rhyolite exposed on the path up to Les Hurets. BGS © UKRI 2020.

Photo 7: Spherulites (probably in the Middle Bouley Bay Ignimbrite) in a small exposure on the path up to Les Hurets. BGS © UKRI 2020.

Photo 8: View looking north to outcrops at the southern end of Les Hurets from the Les Charrierés du Bouley (C102) road. The Old Guardhouse on the top of Les Hurets can just be seen in the top left-hand corner of the image. BGS © UKRI 2020.

Photo 9: Most of the rock outcrops at the southern end of Les Hurets are surrounded by high, dense gorse bushes, making access very difficult, but the views across Bouley Bay towards the north-east corner of Jersey are spectacular on a clear day. BGS © UKRI 2020.

Photo 10: Thin veins of jasper and white quartz within brecciated Bouley Rhyolite. BGS © UKRI 2020.

Photo 11: Flow banding (left-hand side of image) and clusters of spherulites, which resemble bunches of grapes (right-hand side of image). BGS © UKRI 2020.

Photo 12: Complex folding of flow banding within the reddish-purple Middle Bouley Bay Ignimbrite. BGS © UKRI 2020.

Photo 13: Spherulites in a loose block of the Bouley Bay Ignimbrite Formation on the beach. BGS © UKRI 2020.

Photo 14: Cross-sections through large (up to 5 cm in diameter) spherulites in a loose, wave-polished block on the beach. These cross-sections show that the spherulites are built up of concentric shells of radiating fibrous feldspar, which is particularly clearly seen in the outermost rim of the large spherulite in the centre of the image. Individual spherulites are nucleated on crystallites of feldspar and quartz. BGS © UKRI 2020.

Photo 15: Coalescing spherulites in a loose, bright green block of the Bouley Bay Ignimbrite Formation on the beach. BGS © UKRI 2020.

Photo 16: Reddish-purple tuff/ignimbrite within the Middle Bouley Bay Ignimbrite exposed on the beach. The rock displays a eutaxitic texture (flattened and stretched pumice shards) that is more prevalent in the bottom part of the image. Less deformed, cuspate shards occur in the upper part of the image. BGS © UKRI 2020.

Photo 17: Description from Thomas - Lower Bouley Ignimbrite. Fragments of pink ash, and elongated, dark green, collapsed pumice fragments show parallel alignment in the pale green groundmass of this welded ash-flow. BGS © UKRI 2020.

Photo 18: Pumiceous texture within the Bouley Bay Ignimbrite Formation. BGS © UKRI 2020.

Photo 19: Cliff section through the 8 m raised beach and overlying boulder-scale head deposits. The section, which exceeds 12 m in height, occurs at the landward edge of the middle part of the beach at Bouley Bay. BGS © UKRI 2020.

Photo 20: Close-up of gravelly head deposits, composed of angular clasts of volcanic rocks in a matrix of coarse sand. The gravelly head directly underlies the gravel of the 8 m raised beach. BGS © UKRI 2020.

Photo 21: Close-up of the gradational contact between the rounded cobbles of the 8 m raised beach and the underlying gravelly head deposits. BGS © UKRI 2020.

Photo 22: Section through the 8 m raised beach and underlying gravelly head deposits. The raised beach gravel comprises a lower unit of rounded pebbles and cobbles (right-hand side of the image), a middle unit of well-rounded imbricated cobbles and sub-rounded boulder gravel (middle-right part of the image) and an upper unit of well-rounded, fine-to-coarse gravel (upper right part of the image). The lower and middle units merge in the middle and at the left-hand side of the exposure. Crude subhorizontal bedding is present within the indurated gravelly head, which underlies the raised beach gravel, to the right of the rucksack. BGS © UKRI 2020.

Photo 23: The old guardhouse made from locally sourced building stones. BGS © UKRI 2020.

Photo 24: Granitic rocks form the door and window surrounds, as they were fairly uniform and could be easily sculpted. BGS © UKRI 2020.

Photo 25: Conglomerate blocks form much of the walls; they were more difficult to shape. BGS © UKRI 2020.

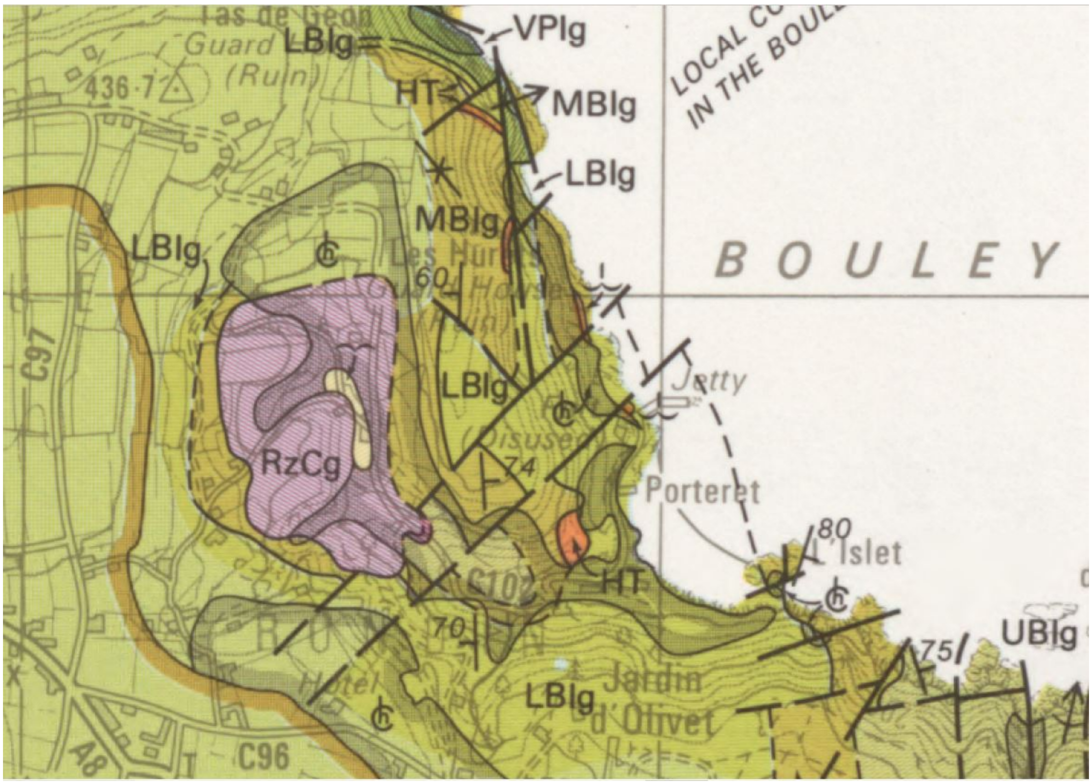
Map of the site boundary on a topographic base

Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph

Imagery ©2020 Government of Jersey.

Published geological map of the site



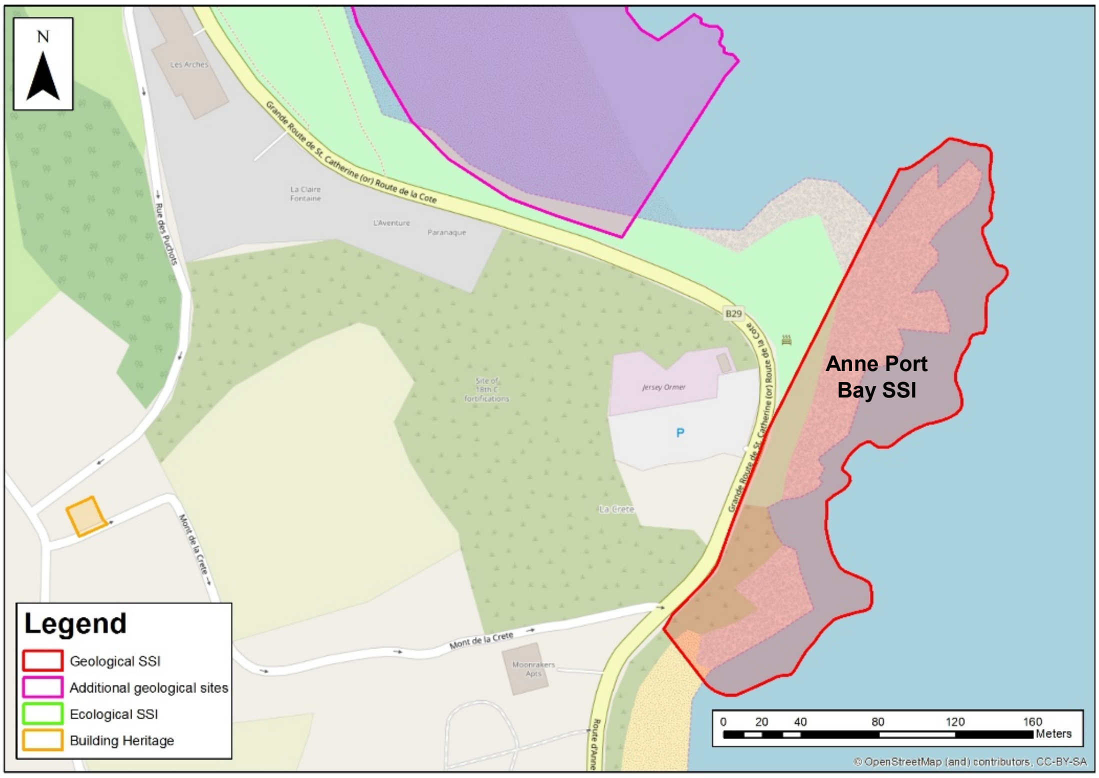
Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.6 SITE NAME: ANNE PORT, SSI

Site Information:
Located on the east coast of Jersey, Anne Port (referred to as 'Jersey's Giant's Causeway') is an existing SSI due to the presence of well-developed columnar jointing within the Bouley Rhyolite Formation (U-Pb zircon age 583 ± 3 Ma; Miller *et al*., 2001). The site also displays excellent exposures of the St John's Rhyolite Formation, a sequence of rhyolites and agglomerates that contain a range of igneous textures, including flattened pumice and volcanic glass shards as well as flow structures. The volcanic rocks are intruded by a number of composite basic dykes. The Bouley Rhyolite and St John's Rhyolite formations may represent the eruptive equivalents of the South-west and *South-east igneous complex*es, which were emplaced during the Cadomian Orogeny. In the sea cliffs, the igneous bedrock is directly overlain by a much younger boulder head deposit. Although it is restricted by tides, the site is much safer to walk across than Giffard Bay, and it is more accessible than the Les Rouaux and Les Hurets, Bouley Bay sites. Anne Port shows different features that are not present at these other sites, and the stratigraphical relationships between the rock units and some of their features are more clearly exposed than at the other sites. The columnar-jointed Anne Port Rhyolite (part of the Bouley Rhyolite Formation) at Anne Port was sampled by Miller *et al.* (2001), making this site of interest to professional Earth scientists and the public alike.

National Grid Reference: Mid-point: 48306, 68095 North end: 48362, 68239 South end: 48251, 67950	**Site Type:** Natural section/exposure
Site Ownership: Public	**Current Use:** Open country, coastal
Field Surveyors: S Arkley and C Auton	**Current Geological Designations:** Geological SSI
Date Visited: 15 and 17 October 2019	**Other Designations:** None known

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran (late Precambrian)	**Formation:** St John's Rhyolite Formation
Rock Types: Anne Port Ignimbrite	
Age: Ediacaran (late Precambrian)	**Formation:** Bouley Rhyolite Formation
Rock Types: Anne Port Rhyolite and Anne Port Andesite	
Age: Quaternary	**Formation:** Head
Rock Types: Poorly sorted deposit containing angular and tabular blocks of local bedrock in a sandy/gritty matrix	

Site Description:

Introduction

Anne Port is an existing Geological SSI located on Jersey's east coast. It reveals a succession of predominantly rhyolitic volcanic rocks assigned to the Bouley Rhyolite and St John's Rhyolite formations. At this site, the Bouley Rhyolite Formation comprises five discrete rhyolite units, including the 'Anne Port Rhyolite', and a thin andesite. These extrusive igneous rocks were later intruded by a lamprophyre dyke. The site is most notable geologically for the columnar jointing developed within the Anne Port Rhyolite, which forms the uppermost rhyolite unit within the Bouley Rhyolite Formation. This has led to the site being known as 'Jersey's Giant's Causeway' due to its similarity to the columnar-jointed basaltic lava flows seen at the world heritage site in County Antrim, Northern Ireland. In a 2005 poll of Radio Times readers, the Giant's Causeway was named the fourth-greatest natural wonder in the United Kingdom. Although the columnar jointing within the rhyolite at Anne Port Bay is on a much smaller scale, many of the features seen at the Giant's Causeway are present at the Jersey site. The volcanic rocks at Anne Port Bay are tilted; consequently, many of the smaller-scale features developed within the flow, such as flow banding and platy jointing, are more accessible than at the Giant's Causeway.

The rhyolites at Anne Port Bay were probably extruded as a series of subhorizontal flows, which were tilted due to the later tectonic deformation of the bedrock. The columnar jointing formed as the originally hot Anne Port rhyolite flow began to slowly cool. These contraction joints formed perpendicular to the upper and lower surfaces of the flow and propagated downwards into the rhyolite as it cooled, resulting in the characteristic hexagonal pillar-like structures. The size of the columns is thought to be primarily determined by the speed at which the rhyolite cooled. Although many of the columns are hexagonal in shape, four-, five- and seven-sided columns are also present. Originally, horizontal fractures or platy joints within the rhyolite divided the columns into a series of stacked, tabular blocks or 'biscuits'. The curved nature of many of these originally horizontal fractures resulted in the formation of so-called 'ball-and-socket' joints.

Bedrock Units

St John's Rhyolite Formation (Jersey Volcanic Group)

The locally named Anne Port Ignimbrite is the uppermost unit of the St John's Rhyolite Formation and it is exposed seaward of the coastal defences on the foreshore and headland in the northern part of Anne Port Bay (Photos 1–3). A detailed geological map of the Anne Port Bay site and the adjacent area was produced by Bishop and Bisson (1989, figure 9; included in this report); it shows that the Anne Port Ignimbrite generally dips north-west at 38–89◦ and is directly overlain by the Anne Port Rhyolite (see below), which dips north-north-west at 47–78◦. Bishop and Bisson (1989) describe the Anne Port Ignimbrite as being typically fine-grained and up to 50 m thick (Photo 3). The lower part of the unit possesses a eutaxitic fabric, which passes upwards into a largely parataxitic ignimbrite containing large, xenolith-rich patches (Photo 4). Bishop *et al.* (2003) note that the ignimbrite also contains conglomeratic lenses that exceed 1 m in thickness and that a debris flow, with blocks up to 50 cm in diameter, occurs at the top of the unit.

Bouley Rhyolite Formation (Jersey Volcanic Group)

The volcanic Bouley Rhyolite Formation comprises a sequence of five rhyolite units, which are interpreted as individual flows and typically possess autobrecciated tops (Photo 5), rubbly bases (Photo 6) and flow-banded middle portions (Photo 7). However, Bishop *et al.* (2003) described the rubbly units at the base of the rhyolites, which contain angular boulders up to 3 m in diameter, as debris flows. An unusual domed structure (Photo 8) observed in one of these volcanic breccias was interpreted by Nichols and Blampied (2016) as a gas bubble. If this interpretation is correct, then this structure potentially records the escape of hot volcanic gases during the deposition/formation of the volcaniclastic breccia, possibly immediately prior to the eruption of the overlying flow-banded rhyolite (Photo 8). A vertical section through the Bouley Rhyolite Formation was published by Bishop and Bisson (1989, figure 12). The Anne Port site is recognised geologically for the columnar jointing developed within the flow-banded portion of the uppermost rhyolite (Flow 5 of Bishop and Bisson, 1989). This is the thickest of the flows and comprises a 130-m-thick unit of flow-banded rhyolite (Photos 11–16) sitting upon a rubbly base; the autobrecciated top of this flow is not seen. Smaller-scale structures, notably flow banding and flow folding, are well developed in the central portions of the rhyolites (Photos 17 and 18). Snowflake textures formed in response to the partial devitrification of the originally glassy rhyolite are also evident in several exposures at Anne Port. Comparable devitrification textures, including spherulites, have been described in the Bouley Rhyolite Formation exposed at the Les Hurets, Bouley Bay site and in polished pebbles of rhyolite on the beach at Giffard Bay. The third and fourth rhyolites at Anne Port are separated by the Anne Port Andesite, a thin (1–3 m thick), dark grey, fine-grained vesicular andesite that has previously been interpreted as an intrusion. Lithologically, this andesite has been compared to the Giffard Andesite from within the Bouley Rhyolite Formation at Giffard Bay and rocks belonging to the older St Saviour's Andesite Formation (Bishop and Bisson, 1989).

Implications of correlations with dated and undated units within the Bouley Rhyolite Formation at other sites

A published U-Pb age of 583 ± 3 Ma (Miller *et al.*, 2001) was obtained from zircons in samples collected from the 130-m-thick, columnar-jointed rhyolite at Anne Port (Flow 5 of Bishop and Bisson, 1989). This rhyolite occurs near the base of the formation as a whole. Consequently, this places a maximum age constraint on the Bouley Rhyolite Formation.

Minor intrusions

A N–S-trending mica-lamprophyre dyke has been mapped cutting the Anne Port Rhyolite west of La Crête Point (IGS 1982), but its position appears to be at variance with the N–S-trending lamprophyric dyke encountered during this study (Photo 19). This sub-vertical, up-to-80-cm-thick dyke has well-developed chilled margins (up to 20 cm wide) along the host rhyolite. The dyke appears to be lithologically similar to a mica-lamprophyre dyke observed cutting the Giffard Rhyolite exposed in the middle of the Giffard Bay site.

Quaternary Sediments and Landforms

Two small patches of raised beach gravel have been mapped resting on bedrock. These have been assigned to the 8 m raised beach, but at the time of the site visit they were poorly exposed and therefore not examined in detail. A poorly sorted bouldery head rests directly on haematite-stained Anne Port Ignimbrite in a cliff above the high-water mark on the landward (western) edge of the site (Photo 20). The deposit comprises angular and tabular blocks of andesite and rhyolite in a coarse, sandy and gritty matrix. The tabular clasts show moderately developed imbrication in the lower part of the unit.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	There is a limited number of car park spaces along the road at the top of the beach (Route de la Cote). Some additional parking is available at La Crête at the northern end of the bay in a former quarry. A small picnic area lies opposite the car park; it provides views across the northern part of the site, including views of the spectacular columnar jointing. Two bus routes go through Anne Port; the bus stop is in the middle of the bay at the top of the slipway.
Access to the site	There is open access onto the beach/foreshore via a well-constructed slipway in the middle of the bay. Anne Port has a large, sandy beach with shingle near the seawall that provides safe, easy access to the southern part of the site. Note that the sand is largely covered at high tide. Many, although not all, of the bedrock exposures are in the intertidal zone and will usually be covered at high tide.
Safety of access	There is good, safe access onto the foreshore. However, all visitors should be aware of the tide times and access routes when planning a visit.
Safety of exposure(s)	They are reasonably safe. The intertidal bedrock exposures have an uneven, water-worn surface and are often slippery with algae and seaweed – stout footwear is recommended.
Current condition	Many rock exposures are clean and free of vegetation. However, in the intertidal zone the rocks may be covered by barnacles, algae and seaweed.
Current conflicting activities	None known
Restricting conditions	Many of the bedrock exposures are in the intertidal zone and therefore they are covered at high tide. The Quaternary sections, although they lie above the normal high-tide mark, may be difficult to access when the tide is in.
Nature of exposure(s)	Bedrock exposures are found in the intertidal and backshore areas (areas normally above the high-tide mark but washed by the sea during storms). Quaternary deposits can be observed in some cliff sections beneath the road.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Site of La Crete Guardhouse, shown on the Plees Map 1817 (HER Number 0700315). Site of Fortifications (1563 to 1795) shown on the Richmond Map 1795 (HER Number 0700338). Anne Port Bay was originally going to be included within the Archirondel Breakwater (the southern arm of the large harbour designed for Jersey's east coast). However, by the time work started in 1847, the plans had been altered and the breakwater was moved northwards to come from Archirondel Tower. In 1849, work stopped on the southern breakwater (to focus on completing the northern breakwater) and was never completed. The northern breakwater (St Catherine's) was completed and still exists today.
Aesthetic landscape	Coastal – Anne Port is a relatively small, secluded bay on Jersey's east coast with panoramic views, and although it has always been a tourist attraction, it is relatively quiet and unspoilt. It is reportedly possible to see France on a clear day. It is very clean – no litter was seen.
History of Earth science	No known association

Economic geology	Discontinuous, narrow veins of red haematite and silvery, crystalline metallic haematite have been reported in the volcanic rocks between Anne Port and La Crête Point (http://www.jerseygeologytrail.net/Economic_Resources.shtml). Quarrying of the Anne Port Rhyolite formerly took place just inland of the site (now La Crête Car Park).

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	International	Excellent	Detailed descriptions	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The Anne Port site is regarded as the best of the visited sites containing volcanic sequences. Although the intrusive rocks exposed at the site are less varied than those observed at Giffard Bay, they are more varied than those at Les Hurets, Bouley Bay. The stratigraphical relationships between the rock units are also more clearly exposed here than at the other sites. The geological features that the volcanic rocks display are abundant, clearer to see and easier to recognise, and therefore interpret, than they are elsewhere. The zircons dated from the columnar-jointed lava flow in the Anne Port Rhyolite near the top of the Bouley Rhyolite Formation have yielded a U-Pb age of 583 ± 3 Ma. This is regarded as the most reliable age available from any of the volcanic rocks within the *Jersey Volcanic Group*, and as such it is critical in establishing the relative individual age components of all of the other volcanic sequences on the Island.

Assessment of Site: Current Site Usage

Community	The picturesque Anne Port attracts visitors all year round. The gently shelving beach is good for swimming and the stone-built slipway is good for launching small boats. Although facilities are limited, there are public toilets. A number of locals live around the bay and there are some holiday lets, but parking is limited for those travelling from further afield. The bay generally appears to be well used but it is never too busy.
Education	The impressive, large-scale columnar jointing is a key feature at this site that any visitor should be able to observe, and it could be used as a great hook to interest non-geologists. With some explanatory information from a teacher, guidebook or information board, Jersey's volcanic past could be superbly explored through the varied lithologies, structures and relationships visible here. The existence of a published paper about the Anne Port Rhyolite gives the site additional importance to those in higher education and research groups.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Like all coastal locations, the site is subject to high-energy weathering and erosion. However, the bedrock exposures are fairly robust. The cliff sections, through the head deposits, at the back of the beach are mainly above the normal high-tide mark. Some washing and minor erosion of the cliffs by storm waves probably helps to keep the few sections that are present exposed (free of vegetation).
Potential use	The columnar jointing is a great asset to this site and should be used as a hook to engage non-geologists in the world of volcanic rocks and/or geology in general. The site has good safe access and is within walking distance of Mont Orgueil Castle (a tourist hotspot). The site could be part of a Jersey geological trail or an extended geological walk in the Gorey area, or information on the site could be included in literature/leaflets describing the walks along the east coast.

Site Photos:

Photo 1: General view looking north from Anne Port Bay to the bedrock exposures in the Anne Port Ignimbrite of the St John's Rhyolite Formation (left foreground) and the overlying Anne Port Rhyolite of the Bouley Rhyolite Formation forming the headland and rock pinnacle at La Crête Point (right background). BGS © UKRI 2020.

Photo 2: Coastal defences at the northern end of Anne Port Bay, with exposures of the haematite-stained Anne Port Ignimbrite of the St John's Rhyolite Formation on the foreshore. BGS © UKRI 2020.

Site Photos:

Photo 3: Anne Port Ignimbrite at the top of the St John's Rhyolite Formation. BGS © UKRI 2020.

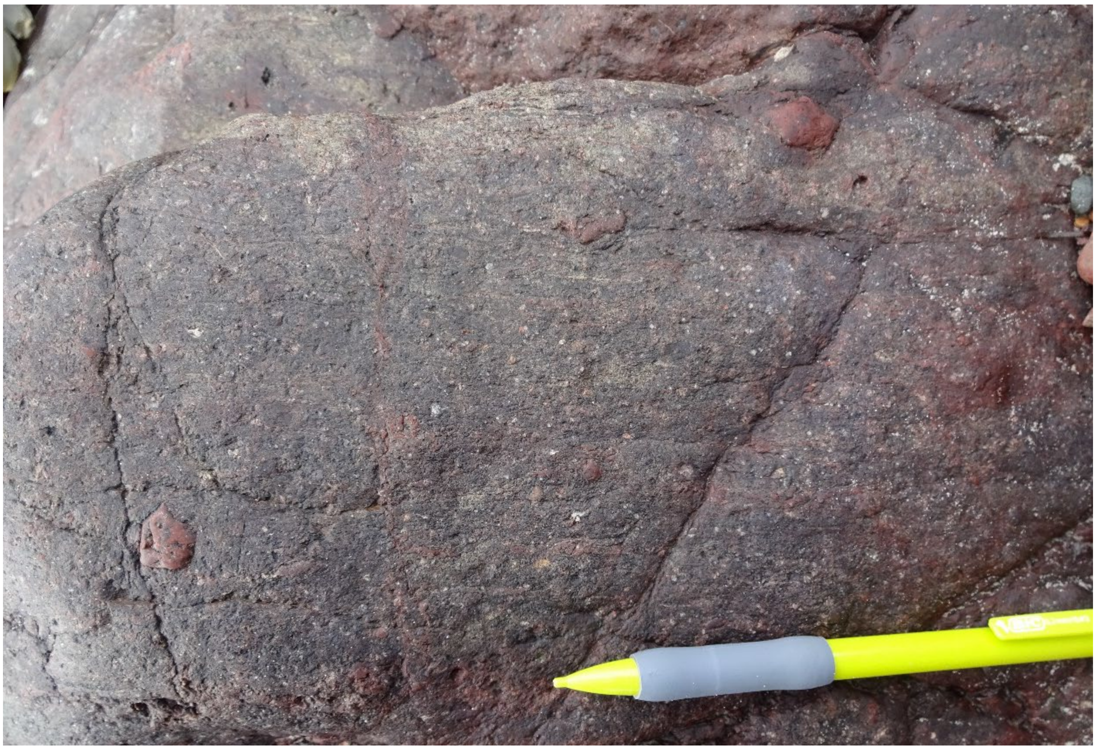


Photo 4: Xenolith-rich patch within the Anne Port Ignimbrite (St John's Rhyolite Formation) containing xenoliths of aphyric rhyolite. The groundmass of the rock is fine-grained, with traces of parataxitic texture. The rock is stained and, in places (top of image), replaced by haematite. BGS © UKRI 2020.

Photo 5: (BGS Ref: P00503) Autobrecciated top of a rhyolite flow from the Bouley Rhyolite Formation comprising randomly orientated flow-banded blocks of rhyolite. GM Thomas, 1976. BGS © UKRI 2020.

Photo 6: (BGS Ref: P005404) Rubbly base of a rhyolite flow. Numerous rounded to angular boulders, mainly rhyolitic, in the basal part of a rhyolite flow in the Bouley Rhyolite Formation. GM Thomas, 1976. BGS © UKRI 2020.

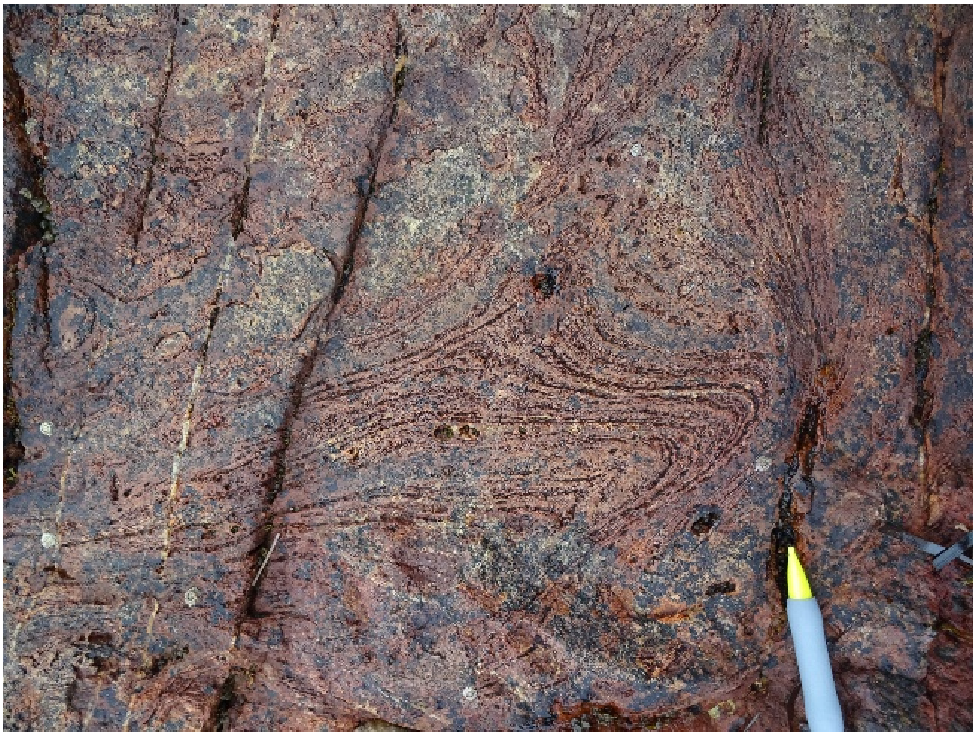


Photo 7: Flow folding in rhyolite. BGS © UKRI 2020.

Photo 8: Large gas bubble in a volcanic breccia. BGS © UKRI 2020.

Photo 9: General view looking north, showing the rubbly base of a rhyolite flow in the Bouley Rhyolite Formation (foreground) and the transition into the lighter coloured columnar-jointed unit (background). BGS © UKRI 2020.

Photo 10: Columnar-jointed rhyolite flow. Central portion of the >130-m-thick rhyolite flow at the top of the Bouley Rhyolite Formation, which displays well-developed inclined columnar jointing. BGS © UKRI 2020.

Photo 11: An excellent example of inclined columns in the Anne Port Rhyolite of the Bouley Rhyolite Formation. Columnar jointing is a network of closely spaced joints/fractures in the rock, which formed as the hot rhyolite cooled and contracted (typically into hexagonal columns). The columns formed perpendicular to the top and base of the flow. All of these columns have now been tilted by tectonic forces. BGS © UKRI 2020.

Photo 12: Flow banding in the rhyolite was formed as the rhyolite flowed; as the volcanic rock cooled and contracted, cooling joints perpendicular to the top and the base of the flow formed columns. BGS © UKRI 2020.

Photo 13: Flow banding preserved in rhyolite. Flow banding is caused by the friction of the hot, viscous rock as it flows over a surface. BGS © UKRI 2020.

Photo 14: Looking onto the hexagonal end of a column. BGS © UKRI 2020.

Photo 15: Inclined columnar jointing in the uppermost flow of the Bouley Rhyolite Formation. BGS © UKRI 2020.

Photo 16: Inclined columnar jointing. BGS © UKRI 2020.

Photo 17: Close-up of snowflake texture. BGS © UKRI 2020.

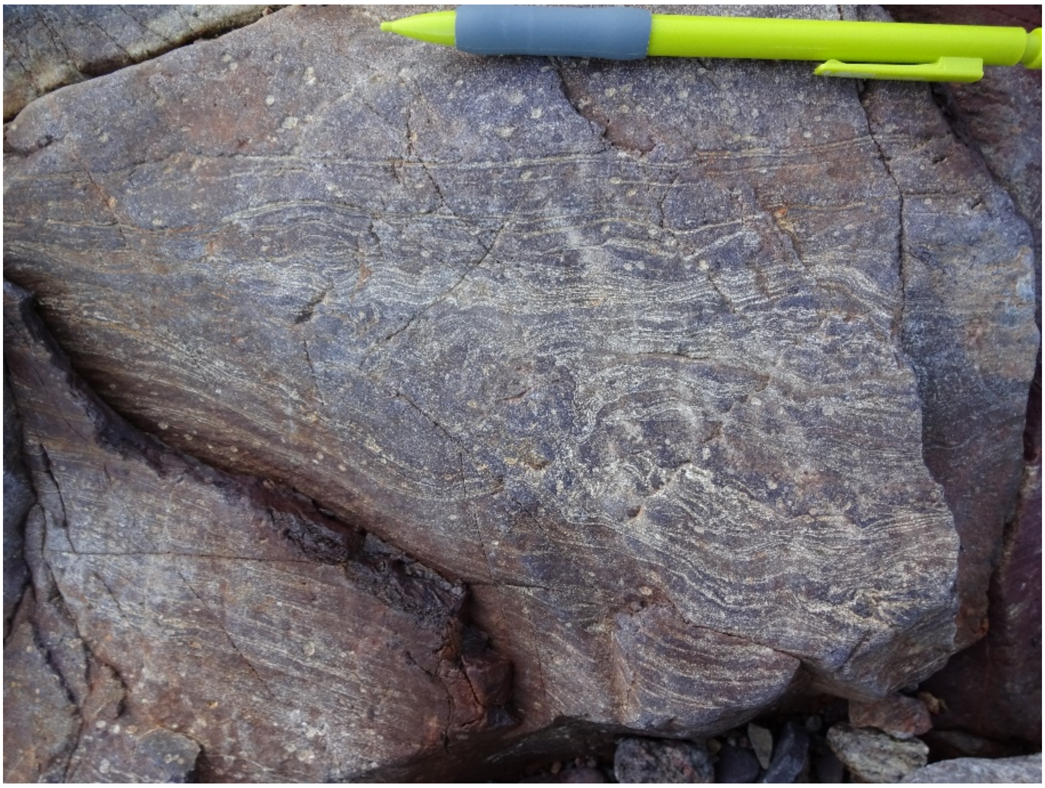
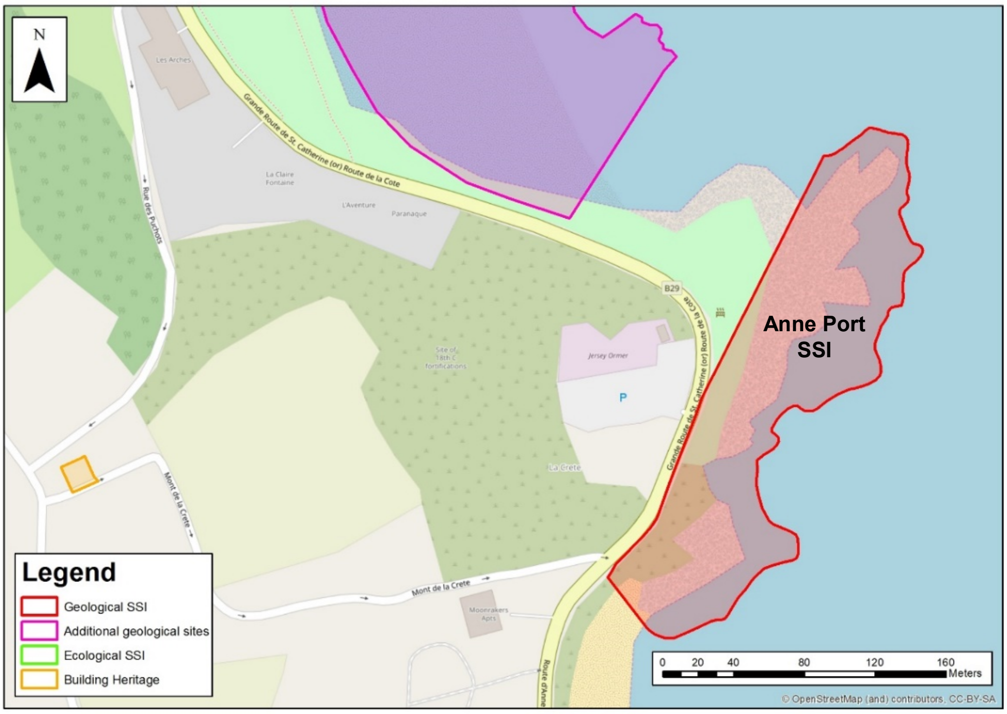


Photo 18: Flow banding in rhyolite, with the development of some snowflakes. BGS © UKRI 2020.

Photo 19: Curved, sub-vertical mica-lamprophyre dyke that is up to 80 cm thick. The dyke trends N–S and has chilled margins, up to 20 cm wide, along a rhyolite of the Bouley Rhyolite Formation. View looking towards the north. BGS © UKRI 2020.

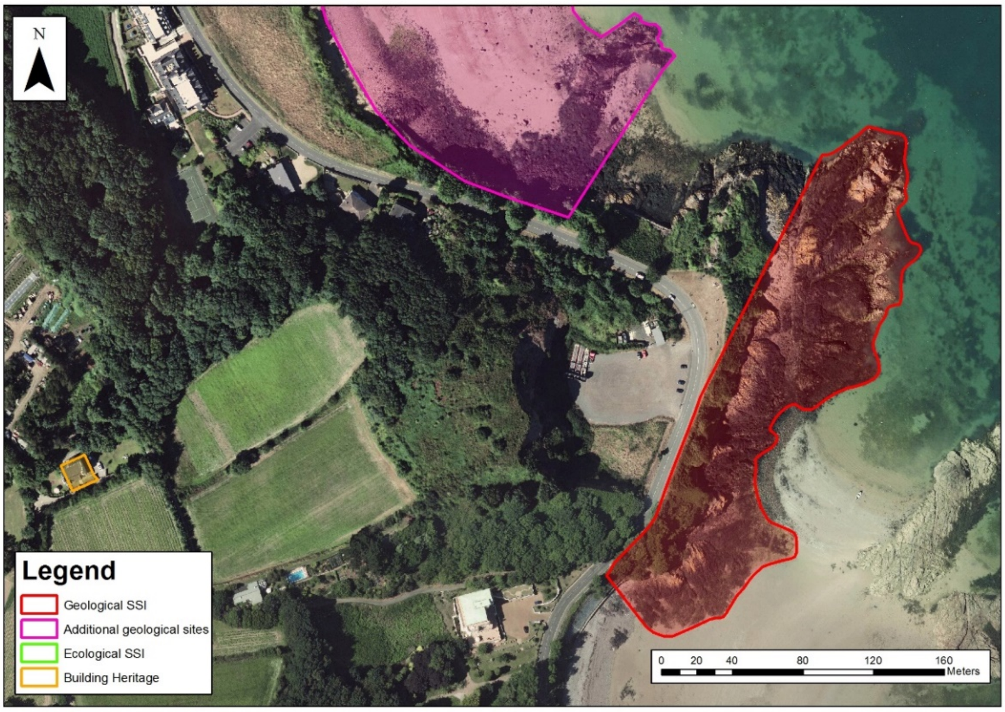
Photo 20: Bouldery head resting on the haematite-stained Anne Port Ignimbrite of the St John's Ignimbrite Formation. Moderately developed clast imbrication is evident in the lower part of the unit (left-hand side of the image). BGS © UKRI 2020.

Map of the site boundary on a topographic base



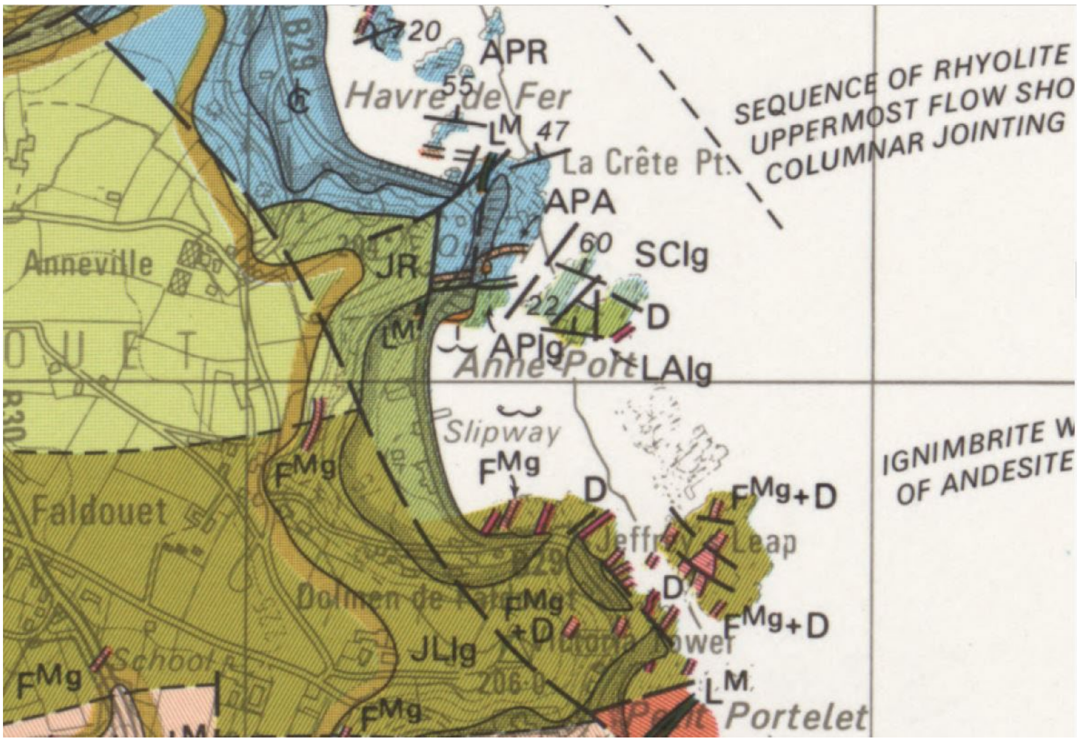
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



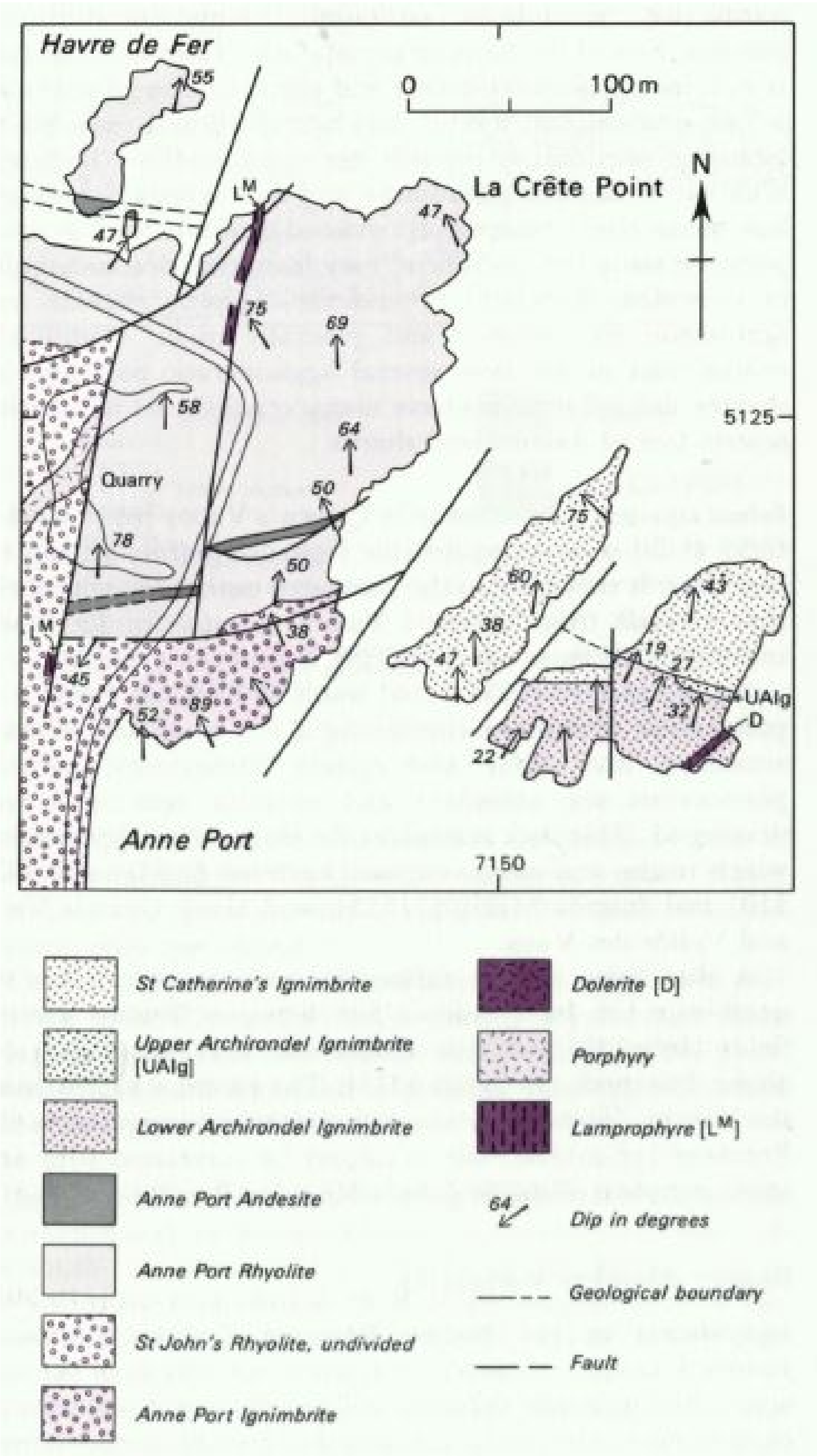
Imagery ©2020 Government of Jersey.

Published geological map of the site

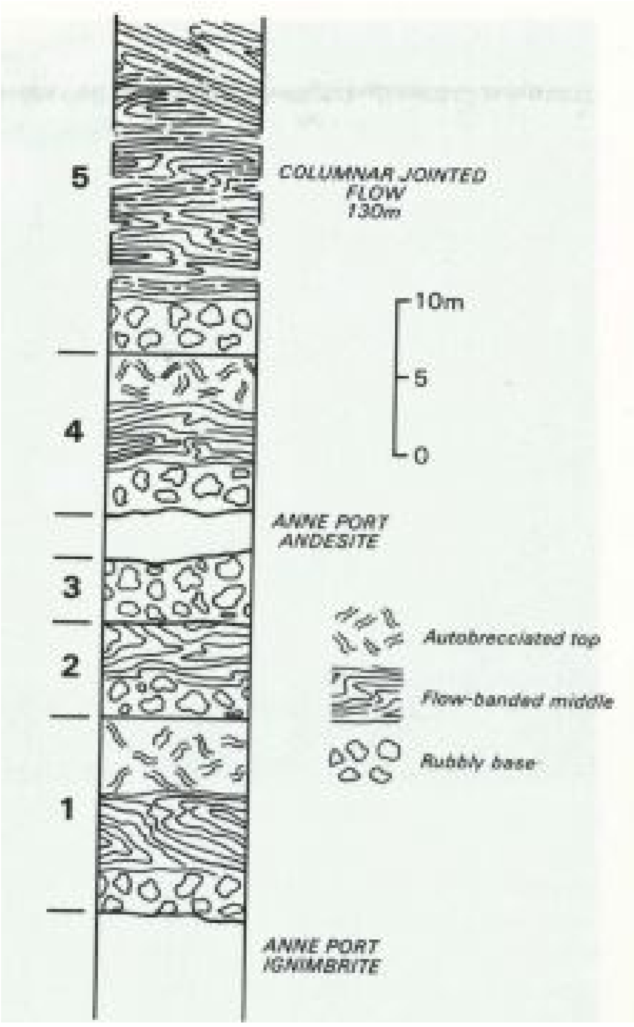


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

Detailed geological map of the Anne Port Site and adjacent ground, reproduced from Bishop and Bisson (1989).



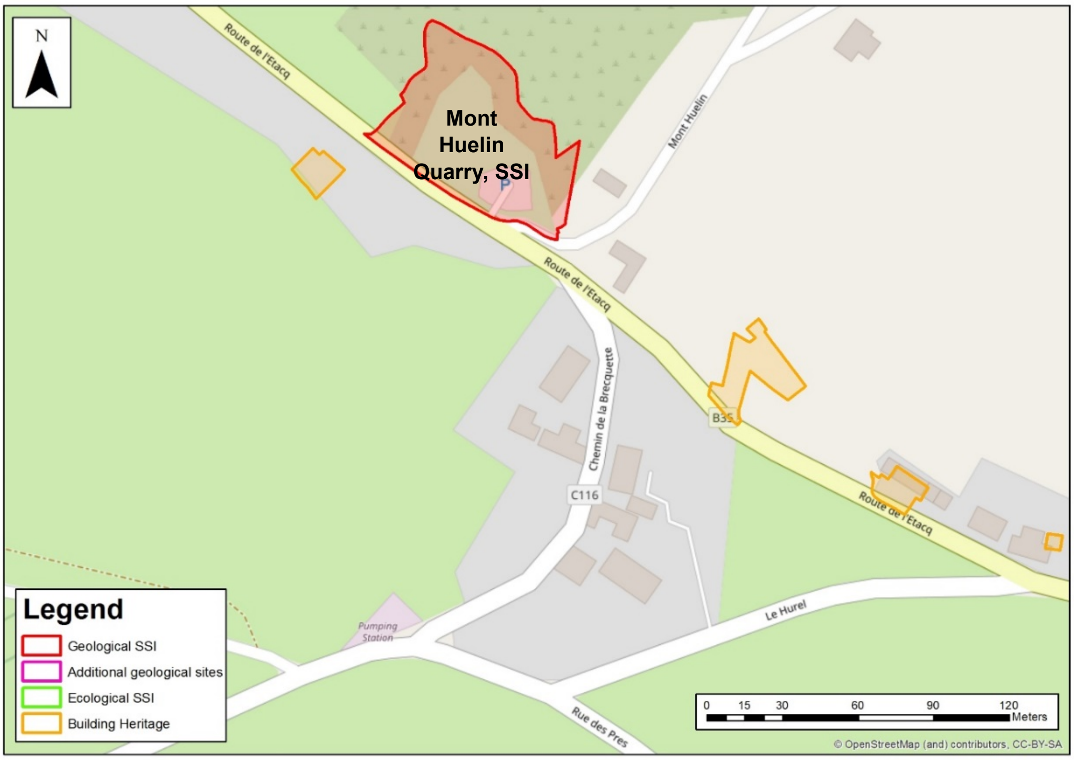
Generalised vertical section through the Anne Port Rhyolite (reproduced from Bishop and Bisson, 1989, figure 12).



7.7 SITE NAME: MONT HUELIN QUARRY, SSI

Site Information:	
This site is a quarry on La Route de l'Etacq, to the north of the hamlet of Le Haut de l'Etacq. The *Jersey Shale Formation* is exposed here where it is in contact with the *North-west igneous complex* and is altered by the heat associated with the intrusion of the granite. The *Jersey Shale Formation* was deposited, as turbidites, in a submarine fan, which formed roughly 587 million years ago and was folded and weakly metamorphosed during the Cadomian Orogeny. The *North-west igneous complex* was emplaced in the Ordovician Period.	
National Grid Reference: Mid-point: 32778, 71363 West end: 32733, 71364 East end: 32816, 71360	**Site Type:** Artificial quarry works
Site Ownership: Part public and part private	**Current Use:** Disused quarry, now used as car parking
Field Surveyors: RS Kendall, S Arkley and M R Gillespie	**Current Geological Designations:** Geological SSI
Date Visited: 23 September and 14 October 2019	**Other Known Designations:** None known

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Latest Precambrian (Ediacaran)	**Formation:** *Jersey Shale Formation*

Rock Types: Sandstone, siltstone and claystone with rare intra-formational conglomerates. At this locality, the rocks are thermally metamorphosed.	
Age: Ordovician	**Formation:** *North-west igneous complex*
Rock Types: Coarse-grained (*St Mary's type*) granite	

Site Description:

Introduction

Exposed at Mont Huelin Quarry is an almost vertical contact between the *Jersey Shale Formation* and the *North-west igneous complex*. The granite intrudes the north-easterly dipping sediments of the *Jersey Shale Formation*. The most recent dates that have been produced for the North-west granite complex are from samples collected at this locality (Miller *et al*., 2001). Xenoliths of the *Jersey Shale Formation* can also be seen incorporated within the granite, close to the contact.

Bedrock Units

Jersey Shale Formation

At Le Mont Huelin, the rocks that comprise the *Jersey Shale Formation* are contact metamorphosed – they were heated by proximity to granite, producing hornfels. This process of recrystallisation has destroyed much of the internal structure. The features typical of this facies of the *Jersey Shale Formation* are better examined at Grand Étacquerel, where they are less affected by metamorphism and a range of internal structures that demonstrate the *Jersey Shale Formation*'s deposition as turbidites in the outer parts of a submarine fan can be examined.

At the most western extent of the exposure, thermal metamorphism *Jersey Shale Formation* has caused the recrystallisation of the mudstones and sandstones that make up the Jersey Shale Formation. Metamorphism makes internal sedimentary features difficult to recognise, but there are the remnants of bedding, which can be seen in the lighter-coloured meta-sandstone layers in the rock.

Age and regional correlation

Miller *et al.* (2001) produced a uranium-lead isotope date for the *Jersey Shale Formation*. The youngest zircons yielded nearly concordant dates of 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma, providing a maximum depositional age for the unit. They also tested zircons from the overlying volcanic rocks (Anne Port Rhyolite), which had an upper intercept date of 582.8 +3/-2.7 Ma; this is considered to be the date of eruption. These dates provide good constraints on the age of the *Jersey Shale Formation*. The *Jersey Shale Formation* has been correlated with the Upper Brioverian rocks of Baie de St Brieuc and the Manche regions of France on the basis of lithological studies (e.g., Graindor, 1957; Dupret *et al*., 1990; Guerrot *et al*., 1989). The Brioverian, in France, is divided into upper and lower sequences, with the Coutances quartz diorite used as a regional time marker (584 ± 4 Ma; Guerrot *et al*., 1989) because it intrudes and metamorphoses the older sequence but not the younger sequence. However, Miller *et al.* (2001) have produced a minimum date for the formation that indicates that it was deposited at or after *c.* 587 Ma, which may suggest that the *Jersey Shale Formation* should be placed in the Lower Brioverian. Alternatively, it may be that the deposition and deformation of the Brioverian volcano-sedimentary sequence was diachronous, which would mean that these lithological and age relationships cannot be applied across the whole region (Miller *et al.*, 2001).

North-west igneous complex

The granite exposed at this site is from the St Mary's granite part of the *North-west igneous complex*. The granite here is coarse-grained and contains tabular crystals of orthoclase or orthoclase perthite, which are visible here as larger, tabular, pinkish crystals. The granite also contains subordinate and smaller plagioclase, abundant quartz, and biotite and hornblende, with zircon and apatite as common accessory minerals.

The *North-west igneous complex* is one of three major intrusion complexes in Jersey. Two main components of the *North-west igneous complex* were distinguished on the geological map of Jersey (IGS, 1982) – St Mary's granite, which underlies more than 90% of the onshore outcrop, and Mont Mado granite, which underlies a sliver of ground at the eastern extremity of the outcrop. Subsequently, the outcrop of St Mary's granite has been divided into several components distinguished by their textural and/or mineral characteristics; they are distributed in a concentric or 'bullseye' pattern. An outer zone is formed of coarse 'porphyritic granite', a middle zone is formed of 'finer-grained granite' and a small central zone is formed of 'biotite granite' (Bland, 1985; Brown *et al*., 1990). This pattern suggests that the *North-west igneous complex* is in fact a single concentrically zoned pluton. Most of the pluton is of granite composition, but bodies of 100 m to 1 km scale formed of diorite, gabbro and lithologically heterogeneous rocks, which formed through the mingling of basic and siliceous magmas, crop out discontinuously within a swathe of ground roughly 2 km wide that extends from St John's Village to the coast around Sorel Point.

The geometry of the bullseye pattern suggests that most of the outcrop of the *North-west igneous complex* is on mainland Jersey, with only about one quarter of the pluton lying offshore; on this basis, the outcrop of the whole pluton would be around 10 x 6 km. However, granitic rocks crop out on the seafloor for a considerable distance to the north and west of north-west Jersey (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the north of the *North-west igneous complex*.

A U-Pb zircon age of *c.* 483 Ma for a sample of St Mary's granite from Mont Huelin Quarry (Miller *et al*., 2001) in the outermost zone of the pluton confirms that the *North-west igneous complex* was emplaced in the Ordovician Period. As such, it is around 100 million years younger than the other two main igneous complexes in Jersey (*South-west igneous complex* and *South-east igneous complex*). The cause of the magmatism that produced the *North-west igneous complex* is not clear, but it may represent a late Cadomian event or it may have been linked to widespread tectonic events around the Iapetus and Rheic ocean realm at this time.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	This site comprises worked quarry faces behind a community car park, so visitors can park within this site.
Safety of access	There is car parking within this site, which is quiet, but care should be taken if there are vehicles moving in this area.
Safety of exposure(s)	This site comprises worked quarry faces. Hard hats should be worn at this locality.
Access	Access is good but would benefit from vegetation clearance, especially to facilitate access to the geological contact.
Current condition	This site is in good condition, although it is overgrown with vegetation. It is presently in use as a car park.
Current conflicting activities	None

Restricting conditions	There are presently no conditions restricting access. The faces are high, so hard hats need to be worn in case of rockfall.
Nature of exposure(s)	The exposure consists of worked quarry faces.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	La Maison de L'Etacq, a listed building on the Richmond Map 1795 (HER Number 0900253). Jubilee Cottages, listed buildings, *c.* 1830s (HER Number 0900083).
Aesthetic landscape	This site is at the base of a ridge that extends approximately east to west in the north-western part of Jersey. It is a feature caused by the different rates of erosion between the hard granite, which forms the higher ground in this area, and the less resistant *Jersey Shale Formation* rocks. As other rocks are visible here, this is a good place to illustrate this concept.
History of Earth science	None
Economic geology	The faces exposed at this site are the product of historic granite extraction.

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Regional	Good	Referenced	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

This site provides an opportunity to examine a relatively simple contact between igneous and sedimentary rocks. Here, the *Jersey Shale Formation* is exposed where it is in contact with the *North-west igneous complex* and is altered by its proximity to the intrusion of the granite. One of the strengths of this site is that the features of interest are very easily accessible, as parking is adjacent to the site.

Assessment of Site: Current Site Usage	
Community	This site is currently used as a car park and an area of green space.

Education	Mentioned in geology guidebooks for Jersey

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The site is vulnerable to natural overgrowth, illegal dumping and development.
Potential use	The main strength of this site is its very accessible nature. The site is already a Geological SSI and is highlighted in geological tour guides for the island. It could easily accommodate interpretation boards and be part of geotrails. This site could also be easily modified for disabled access. This site is most useful for higher or further education, as well as schools.

Site Photos:

Photo 1: General view of the site, facing towards the north. Contact is in the trees on the left side of this picture. BGS © UKRI 2020.

Photo 2: View of quarried granite faces in the centre of the site (facing north), illustrating the large flat joint surfaces within the granite. The faices here are about 25 m high. BGS © UKRI 2020.

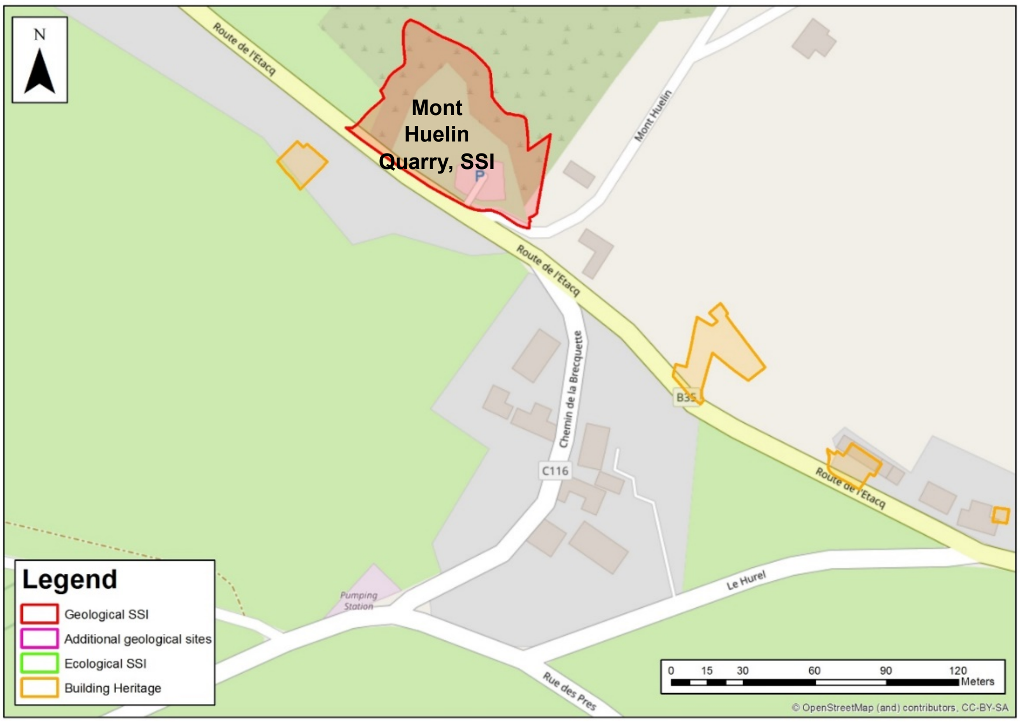
Photo 3: Thermal metamorphism *Jersey Shale Formation* has caused the recrystallisation of the mudstones and sandstones that make up the Jersey Shale Formation. This makes internal sedimentary features difficult to recognise. However, on the west side of the site, you can still see evidence of bedding in the lighter-coloured meta-sandstone layers in the rock. BGS © UKRI 2020.

Photo 4: The granite exposed at this site is from the St Mary's granite part of the *North-west igneous complex*. The granite here is coarse-grained and contains tabular crystals of orthoclase or orthoclase perthite, which are visible here as larger, tabular, pinkish crystals. The granite also contains subordinate and smaller plagioclase, abundant quartz, and biotite and hornblende, with zircon and apatite as common accessory minerals. BGS © UKRI 2020.

Photo 5: General view of the almost vertical contact between the granite on the right and the thermally metamorphosed *Jersey Shale Formation* on the left. BGS © UKRI 2020.

Photo 6: This is a more detailed view of the contact where a possible xenolith of the metamorphosed *Jersey Shale Formation* is incorporated into the intruded granite. BGS © UKRI 2020.

Map of the site boundary on a topographic base

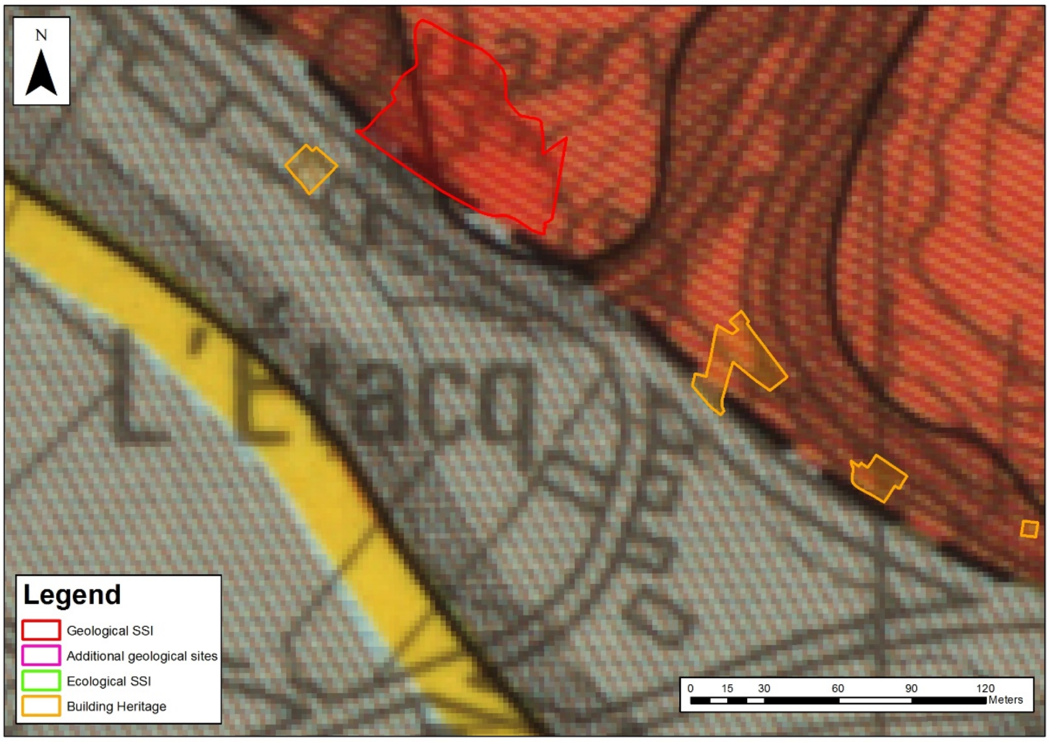


Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph

Imagery ©2020 Government of Jersey.

Map of the site boundary on a published geological map

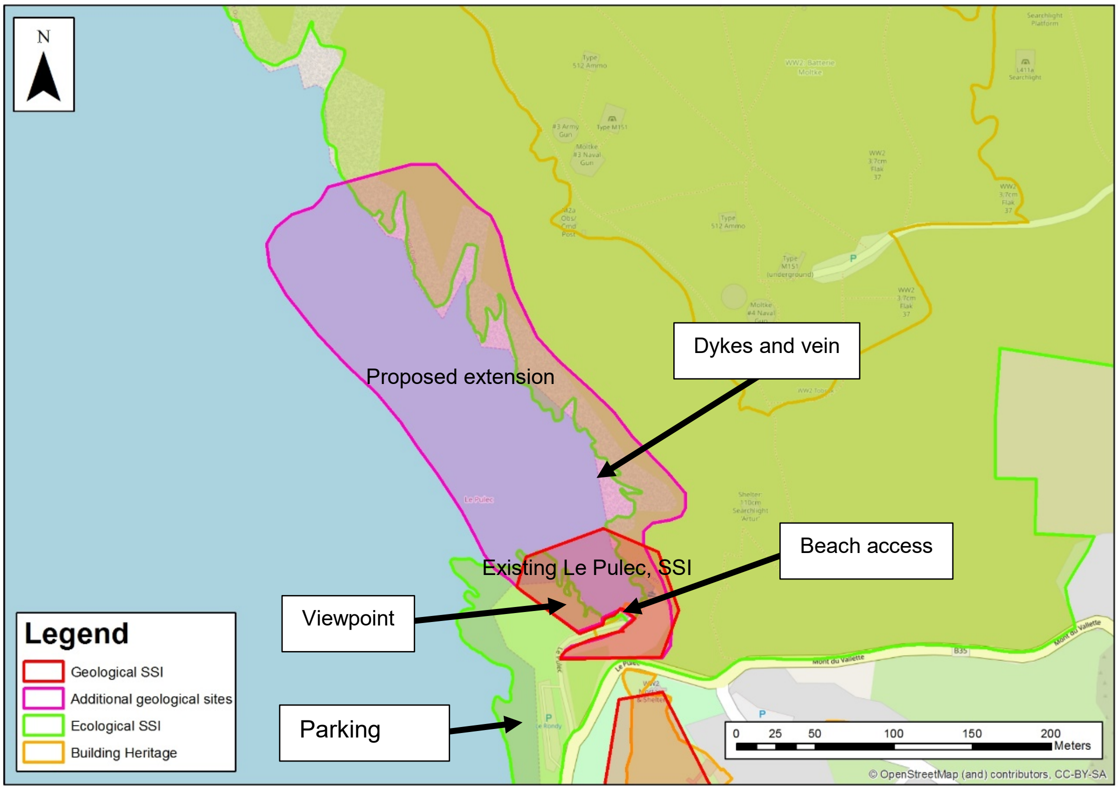


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.8 SITE NAME: LE PULEC, SSI AND PROPOSED EXTENSION

Site Information:	
Le Pulec is the best place in Jersey to observe the contact between a major intrusion and the ‘country rock’ into which it was emplaced. The site also presents good examples of many geological features that typically form around such contacts. The site consists of intertidal outcrops on the north side of Le Pulec, a small bay towards the north end of the west coast of Jersey. The bedrock comprises a turbidite succession in the *Jersey Shale Formation* and granite of the *North-west igneous complex*. This site is equally important for understanding past sea levels across Jersey and the rest of the Channel Islands.	
National Grid Reference: Mid-point: 31597, 72071 West end: 31454, 72172 East end: 31719, 72011	**Site Type:** Natural exposure
Site Ownership: Part public and part National Trust for Jersey	**Current Use:** Open country, coastal
Field Surveyors: M Gillespie and R Kendall	**Current Geological Designations:** Geological SSI
Date Visited: 14 October 2019	**Other Known Designations:** The site area coincides with part of an Ecological SSI (Les Landes) and part of a Building Heritage site (Les Landes Prehistoric Landscape).

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** *Jersey Shale Formation*
Rock Types: Interbedded sandstone and mudstone (turbidite)	
Age: Ordovician Period	**Formation:** St Mary's granite / *North-west igneous complex*
Rock Types: Granite	
Age: Ediacaran Period (late Precambrian)	**Formation:** Probably part of the Jersey Main Dyke Swarm
Rock Types: Mafite (basalt/dolerite)	

Site Description:

Introduction

Le Pulec, a small bay towards the north end of the west coast of Jersey, is the best place in Jersey to observe the contact between a major intrusion and the rocks into which it was emplaced. Here, the contact between the *North-west igneous complex* and the *Jersey Shale Formation* can be traced for at least 100 m along shoreline exposures forming the north-east side of the bay. Le Pulec is a short walk from a car park, but access to the key exposures is restricted by tides, and the area is made slippery by seaweed (Photos 1 and 2). Elevated ground at the south-west corner of the bay (near the car park) provides an excellent viewpoint from which the contact can be seen at low tide (Photo 1). The same contact relationship can be observed in a nearby quarry (described in the site description for the Mont Huelin Quarry geodiversity site); the exposure there is readily accessible but lacks many of the features that can be seen at Le Pulec.

Bedrock Units

Jersey Shale Formation

The *Jersey Shale Formation* is a thick sequence of interbedded mudstone and sandstone with scattered conglomerate beds. The formation is estimated to have a total stratigraphical thickness of around 2,500 m (Bishop and Bisson, 1989). Sedimentary features in the rocks have been used to interpret the environment in which they were deposited; using this evidence, it has been suggested that the *Jersey Shale Formation* is a thick submarine fan deposit constructed from repeated sediment gravity flows on the slope of a continental margin (Helm and Pickering, 1985). The base of the unit is not visible in Jersey, but volcanic rocks of the stratigraphically overlying (i.e., younger) *St Saviour's Andesite Formation* appear to be folded with the *Jersey Shale Formation* along the south coast at St Helier and on the north coast near Belle Hougue Point. The north and south limits of the outcrop are truncated by major intrusions, and in the east, the limit is defined by a disconformity with younger volcanic rocks.

A well-constrained U-Pb age of *c.* 587 Ma for the youngest detrital zircons in a sample of sandstone from the coast close to Grand Étacquerel (Miller *et al.*, 2001) indicates that the sediment of the *Jersey Shale Formation* accumulated late in the Ediacaran Period (late Precambrian). Subsequently, all parts of the unit were weakly metamorphosed and folded at a range of scales; small folds can be seen in some exposures, and the largest folds may be km-scale folds. Two main phases of deformation have been recognised (Helm, 1983, 1984). Early (D_1) folds trend broadly N–S and sometimes have a spaced, axial-planar cleavage. Younger (D_2) structures are major folds that are accompanied by a non-penetrative, axial-planar fabric and a system of conjugate shear faults.

A U-Pb zircon age of *c.* 583 Ma for a layer of volcanic rock that overlies the *Jersey Shale Formation* but is not folded with it (*Anne Port Rhyolite*; Miller *et al*., 2001) indicates that the *Jersey Shale Formation* must have been folded and metamorphosed soon (less than *c.* 4 million years) after it was deposited. The *Jersey Shale Formation* has been correlated with the Upper Brioverian rocks of Baie de St Brieuc and the Manche regions of France on the basis of lithological studies (e.g., Graindor, 1957; Dupret *et al*., 1990; Guerrot *et al*., 1989).

North-west igneous complex

The *North-west igneous complex* is one of three major intrusion complexes in Jersey. Two main components of the *North-west igneous complex* were distinguished on the geological map of Jersey (IGS, 1982): *St Mary's granite*, which forms more than 90% of the onshore outcrop, and *Mont Mado granite*, which underlies a sliver of ground at the eastern extremity of the outcrop. Subsequently, the outcrop of *St Mary's granite* has been divided into several components distinguished by their textural and/or mineralogical characteristics. These are distributed in a concentric or 'bullseye' pattern (Figure 3) and comprise an outer zone of 'coarse granite', a middle zone of 'porphyritic granite' and a small central zone of 'biotite microgranite' (Bland, 1985; Brown *et al*., 1990). This pattern suggests that the *North-west igneous complex* is a single concentrically zoned pluton. Most of the pluton is of granite composition, but bodies of 100 m to 1 km scale, which are made of diorite, gabbro and lithologically heterogeneous rocks formed through the mingling of basic and siliceous magmas, crop out discontinuously within a swathe of ground roughly 2 km wide that extends from St John's Village to the coast around Sorel Point. Extensive outcrops along the north-west coast of Jersey present excellent examples of all the main components of the *North-west igneous complex*.

The geometry of the bullseye pattern suggests that most of the outcrop of the *North-west igneous complex* is on mainland Jersey, with only about one quarter of the pluton lying offshore. On this basis, the outcrop of the whole pluton would be around 10 x 6 km. However, granitic rocks crop out on the seafloor for a considerable distance to the north and west of north-west Jersey (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the north of the *North-west igneous complex* (Figure 7).

A U-Pb zircon age of *c.* 483 Ma for a sample of *St Mary's granite* from Mont Huelin Quarry (Miller *et al.,* 2001), in the outermost zone of the pluton, confirms that the *North-west igneous complex* was emplaced in the Ordovician Period. As such, it is around 100 million years younger than the other two main igneous complexes in Jersey (*South-west igneous complex* and *South-east igneous complex*), and it is not related to them or to the Cadomian Orogeny. The cause of the magmatism that produced the *North-west igneous complex* is not clear, but it may represent a late Cadomian event or it may have been linked to widespread tectonic events around the Iapetus and Rheic ocean realm at this time.

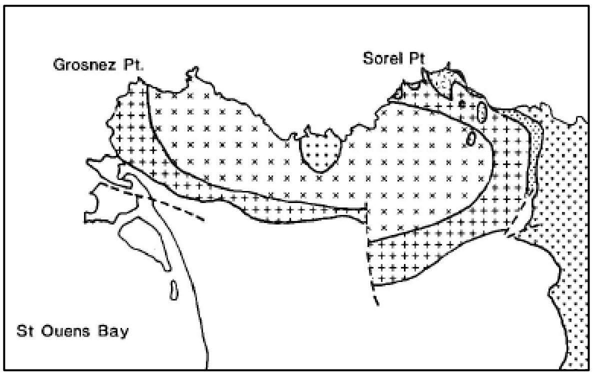


Figure 1. Concentric zoning in the *North-west igneous complex*. Adapted from figure 19 in Brown *et al.* (1990).

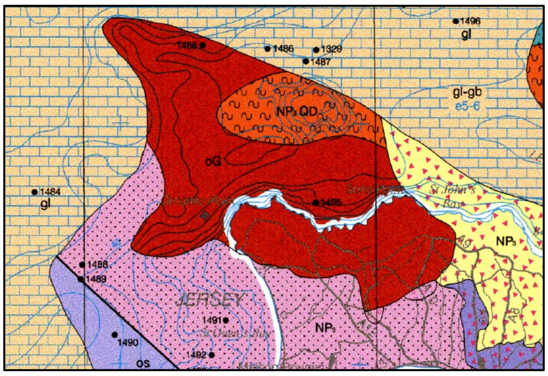


Figure 2. Map of onshore and offshore bedrock geology around north-west Jersey (coastline in white) showing the

	apparent offshore continuation of the *North-west igneous complex*. From BGS (2000).

Jersey Main Dyke Swarm

The *Jersey Main Dyke Swarm* is the name assigned by Lees (1986) to the obvious concentration of dykes that crop out within the E–W-trending area of ground underlain by the two main igneous complexes in south Jersey. The dykes typically are steeply dipping, and most are less than 1 m wide; good coastal exposures reveal that they account for around 10% of the outcrop locally. The swarm is particularly well exposed, and particularly abundant, in the extensive intertidal reef to the west and east of Le Croc in south-east Jersey.

The dykes display strong preferred orientations: E–W in the *South-west igneous complex* and NE–SW in the *South-east igneous complex*. A small proportion of dykes have a broadly N–S trend; these dykes must have opened in a stress regime that was different from the stress regime of those forming the main part of the swarm, indicating that the swarm as a whole had a multistage emplacement history.

Dykes of basic (i.e., basalt and dolerite) composition predominate, but Lees (*ibid*) noted that the dykes cutting the *South-west igneous complex* are mainly dolerite, whereas those cutting the *South-east igneous complex* display a broader range of compositions, including dolerite, microdiorite, lamprophyre and rhyolite (or microgranite). Where they occur together, for example, in exposures on the foreshore at Mont Orgueil, the basic (doleritic) dykes often cut the siliceous dykes. Many dykes are porphyritic; small phenocrysts of plagioclase and ferromagnesian minerals predominate in dykes of basic composition, while phenocrysts of quartz and feldspar occur in siliceous examples. Some dykes are composite, containing both basic and siliceous components; in such cases, basic margins and siliceous centres are common.

The dykes were emplaced during and shortly after the later stages of the assembly of the main igneous complexes (Lees, 1986). Based on whole-rock chemical analyses, Lees (1986) described the swarm as having a calc-alkaline character of a potassium-rich (‘high-K’) type common in magmas generated above subduction zones.

Dykes of similar lithologies, and often with similar trends, occur in other parts of Jersey, although they are relatively rare; many are probably genetically related to the *Jersey Main Dyke Swarm*.

Bedrock Features

The main feature of interest at Le Pulec is the contact between the *Jersey Shale Formation* and *North-west igneous complex*, which can be traced for at least 100 m along the shoreline on the north-east side of the bay. At low tide, the contact is easily picked out due to the contrasting colours of the two units (Photo 1). The contact dips moderately towards the west (as it does in Mont Huelin Quarry); it is generally razor sharp but can be highly convoluted at the outcrop scale (Photo 2).

The contact represents the surface along which a very large mass of extremely hot (probably *c.* 600 ^{o}C) granite magma was juxtaposed against a very large mass of cooler, solid bedrock, deep in the Earth’s crust. Many of the features that typically form in such a dynamic geological environment are displayed at Le Pulec, including chilled margins and xenoliths in the igneous rock, baked margins and minor intrusions in the country rock (Photo 4) and veins produced by hydrothermal processes cutting all rocks. The site is also a good place to observe turbidite layering in the *Jersey Shale Formation* and includes a small fault with associated veins of Cu-Zn carbonate and a dolerite dyke (probably of the *Jersey Main Dyke Swarm*).

Exposures of the *Jersey Shale Formation* at Le Pulec are typically dark grey and water-smoothed. Interbedded layers of dark grey mudstone and lighter sandstone, typical of turbidites, can be observed in some wave-polished surfaces of the outcrop (Photo 10).

However, much of the original sedimentary character of the rock has been obliterated by two phases of metamorphism: the relatively weak dynamic metamorphism associated with the Cadomian event, and the later thermal (or contact) metamorphism associated with the intrusion of the *North-west igneous complex*. The effects of thermal metamorphism become more pronounced as the contact is approached; adjacent to the contact, the rocks of the *Jersey Shale Formation* become texturally homogeneous (hornfelsed) due to thermal metamorphism. It is better to examine the original sedimentary features of the *Jersey Shale Formation* at Petit Étacquerel and Grand Étacquerel.

Superficial Deposits and Landscape

The variety of geomorphological and sedimentary features in the bay at Le Pulec provide evidence of two previous high sea-level stands. The youngest is Holocene in age, and the older feature has not been dated but likely formed in MIS 5e based on evidence from the infill of two gullies adjacent to the slipway, which preserves evidence of only one cold stage. The gullies, cut into rocks of the *Jersey Shale Formation*, have smooth bases and are infilled with rounded pebbles of granite at their bases, with angular rubbly head above. Renouf and James (2010) provide a detailed discussion of the features at this site and have proposed that Le Pulec is a reference site for the interpretation of the 8 m erosional platform for Jersey and the other Channel Islands. The cliffs above Le Pulec are draped with orange-yellow head deposits, which comprise angular granite fragments in a matrix of loess. Photo 1 illustrates the 40 m notch in the cliff profile, which Renouf and James (2010) correlate with the South Hill raised beach.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Small parking area within 200 m of the key exposures
Access	A path and track from the parking area provide easy access to the shore at Le Pulec and a viewpoint over the bay.
Safety of access	The key geological features at Le Pulec can only be appreciated fully by entering the intertidal zone. Currently, some 30 m of very slippery, seaweed-covered ground must be crossed to reach the key exposures.
Safety of exposure(s)	The bedrock exposures comprise rough, rocky ground in the intertidal zone. The ground here may be slippery, and mild scrambling is required to access some parts.
Current condition	Many rock exposures are clean and free of vegetation. However, rocks in the intertidal zone may be covered by barnacles, algae and seaweed.
Current conflicting activities	None
Restricting conditions	The bedrock exposures are mainly in the intertidal zone and will be inaccessible at times. The Quaternary sections, although they lie above the normal high-tide mark, may be difficult to access at any time.
Nature of exposure(s)	Intertidal rock platform and cliffs enclosing the bay, and Quaternary cliff sections

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**

Historic, archaeological and literary associations	Les Landes Area of Prehistoric Activity is an important prehistoric landscape with archaeological sites from the Palaeolithic, Mesolithic and Neolithic. It is of outstanding importance to the archaeological heritage of Jersey and includes evidence of importance to European prehistory (HER Number 0900175; Listed place OU175). Battery Moltke was part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall (HER Number 0900091; Listed building OU0091).
Aesthetic landscape	The bay is scenically attractive.
History of Earth science	None
Economic geology	The extraction of silver and other metals is discussed by Williams (1871) and Ixer and Stanley (1980).

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Local	Excellent	Descriptions	X
Structural geology				
Palaeontology				
Geomorphology	International	Excellent	Descriptions	X

Geoscientific Value of the Site

The geoscientific value of the site is due to the excellent quality and extent of exposures displaying the contact between a major intrusion and country rock, the range of features that are displayed in the contact zone and the importance of the site for understanding past sea levels.

Assessment of Site: Current Site Usage

Community	The site is used by dog walkers and locals who collect the fresh seaweed and use it as fertiliser for their fields.
Education	The site could be of regional value as an educational resource for schools or geological fieldtrips.

Assessment of Site: Fragility and Potential Use of the Site

Fragility	The bedrock exposures are robust.
Potential use	Le Pulec is the best place in Jersey to observe the contact between a major intrusion and the ‘country rock’ into which it was emplaced. The site also presents good examples of many geological features that typically form around such contacts, as well as Quaternary features, making it a good place for research and education about igneous processes and climate change during the Quaternary.

	The main strength of this site is its very accessible nature. The site is already a Geological SSI and is highlighted in geological tour guides for the Island. It could easily accommodate interpretation boards and be part of geotrails.

Site Photos

Photo 1: Looking north-north-west from the viewpoint on the south-west side of Le Pulec to the key exposures on the far side of the bay. The contact between the grey *Jersey Shale Formation*, forming the floor of the bay, and orange St Mary's granite can be traced broadly along the far shoreline. Orange head is visible on parts of the steep slope above the bay. BGS © UKRI 2020.

Photo 2: Looking north-north-west from the shore of Le Pulec to the key exposures of the dark grey *Jersey Shale Formation* and light orange St Mary's granite on the north-east side of the bay. The image shows the large expanse of seaweed that currently must be crossed to reach these exposures and the moderately dipping thin sheets of pale granite cutting the dark grey cliff of the *Jersey Shale Formation*. BGS © UKRI 2020.

Photo 3: The contact between the dark grey *Jersey Shale Formation* and light orange St Mary's granite is revealed in a natural embayment in the cliff on the north side of Le Pulec. The contact dips at a moderate angle towards the photographer (roughly due west). A thin sheet of St Mary's granite cuts the cliff of the *Jersey Shale Formation* on the left, and dark orange head covers the slope above a sea cave in the granite. The field of view is around 6 m from left to right. BGS © UKRI 2020.

Photo 4: Part of the contact, showing its sharp, irregular character, and a chilled margin in the granite. Pen for scale. BGS © UKRI 2020.

Photo 5: A network of granite sheets cutting *Jersey Shale Formation* country rocks near the contact. The yellow notebook is around 15 cm long. BGS © UKRI 2020.

Photo 6: Close-up of the contact, which is razor sharp, with a chilled margin in the granite and a baked zone in the country rock. Pen for scale. BGS © UKRI 2020.

Photo 7: A xenolith of the *Jersey Shale Formation* enclosed in St Mary's granite. The xenolith has a 'glassy' character and rounded surface. Pen for scale. BGS © UKRI 2020.

Photo 8: Aplopegmatite in a boulder. Though it is not observed *in situ*, the aplopegmatite probably formed from vapour-rich magma in the contact zone. Pen for scale. BGS © UKRI 2020.

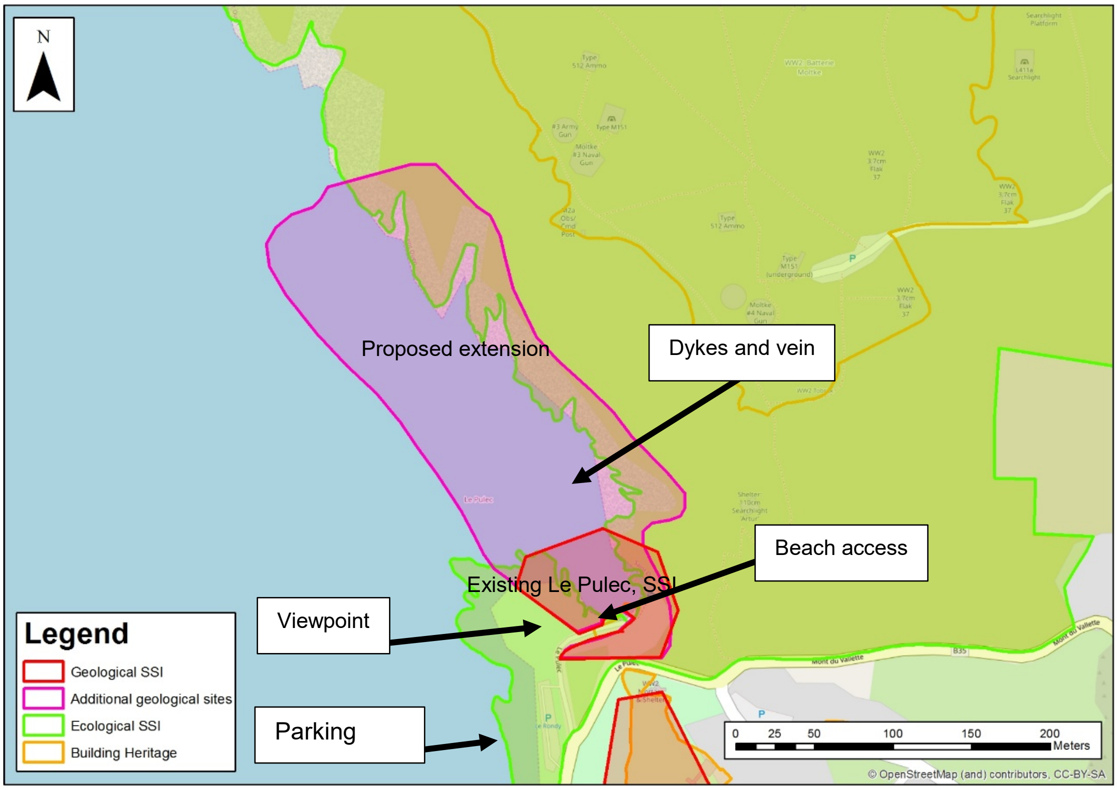
Photo 9: A felsite sheet cutting the *Jersey Shale Formation* near the contact. The sheet is composite, with pink and grey components. Pen for scale. BGS © UKRI 2020.

Photo 10: Sheets of pink St Mary's granite cutting the dark grey *Jersey Shale Formation*, in which original turbidite layering is still visible (dipping gently from the upper right to the lower left). Figure for scale. BGS © UKRI 2020.

Photo 11: Looking south-east along the trace of a mafite dyke (possibly related to the Jersey Main Dyke Swarm) cutting the *Jersey Shale Formation* in the intertidal zone at Le Pulec. In places, the margins of this dyke and other nearby dykes have been exploited by small faults and mineralised veins (see Photo 12). A gully filled with head overlies the trace of the dyke in the slope above. Figure for scale. BGS © UKRI 2020.

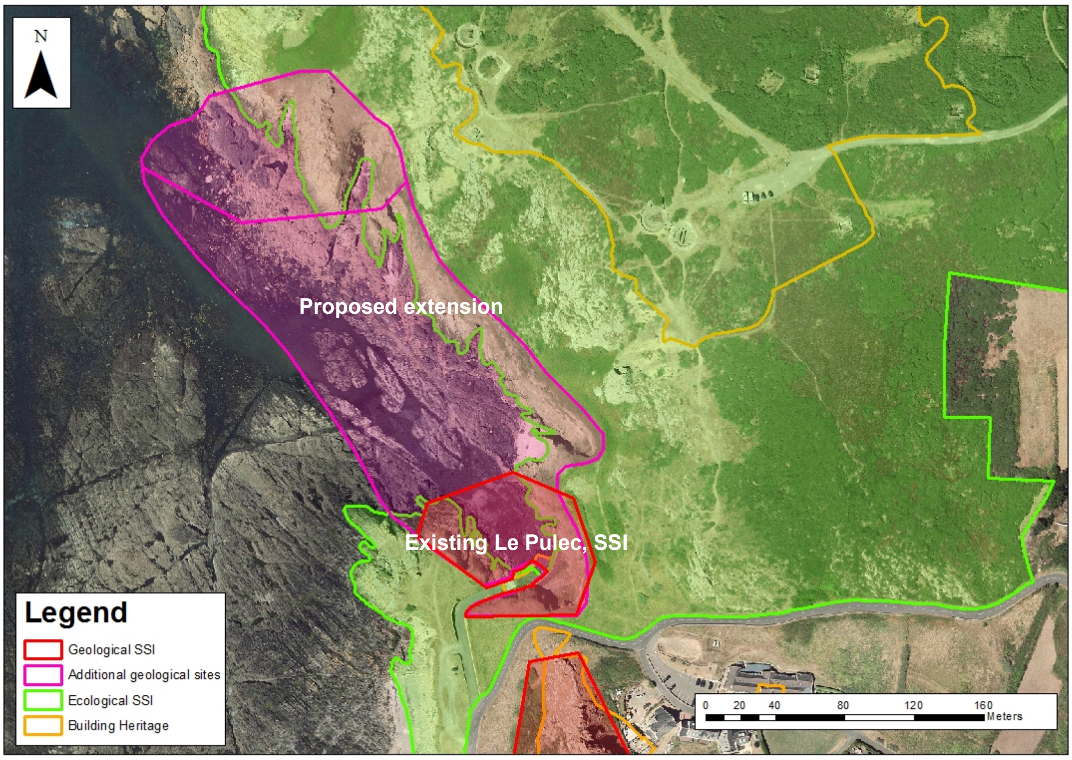
Photo 12: Vein-breccia formed of yellow carbonate cement enclosing angular wall rock fragments in a composite vein formed in association with weak faulting in the *Jersey Shale Formation* in the intertidal zone at Le Pulec. Such veins may have been the source of the Cu and Zn mineralisation that was reportedly exploited in small volume at Le Pulec. Pen for scale. BGS © UKRI 2020.

Map of the site boundary on a topographic base



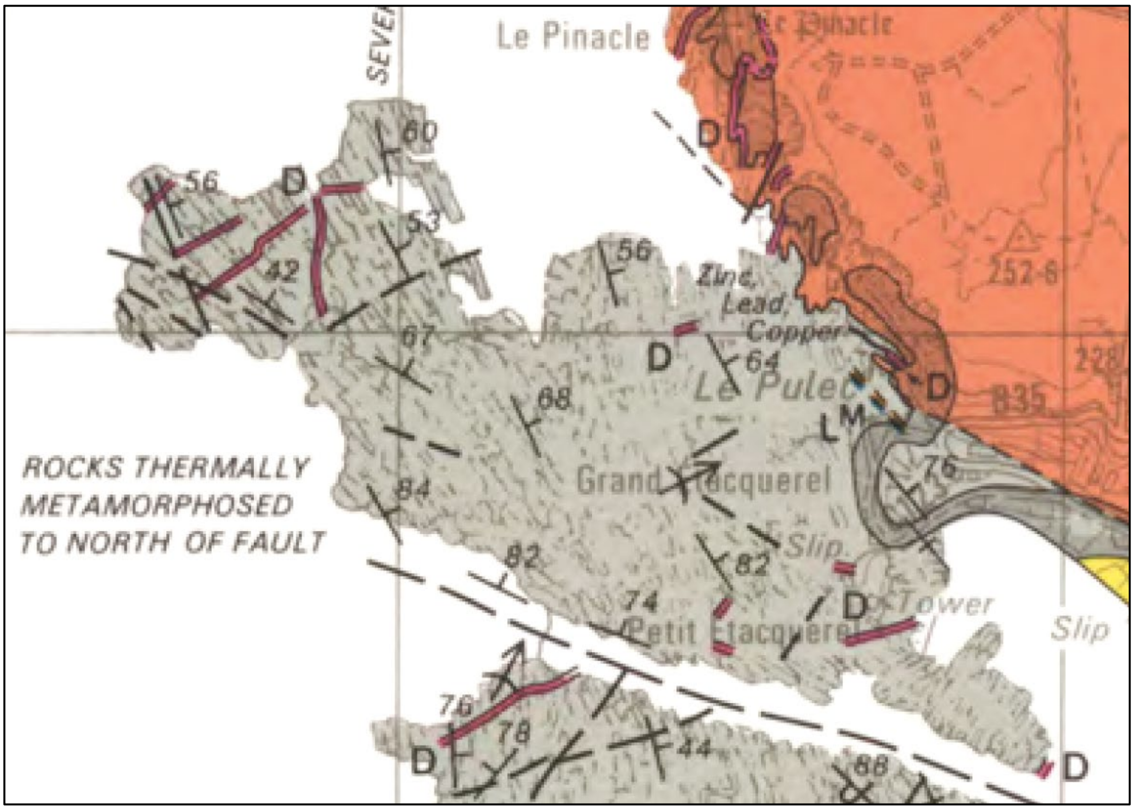
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

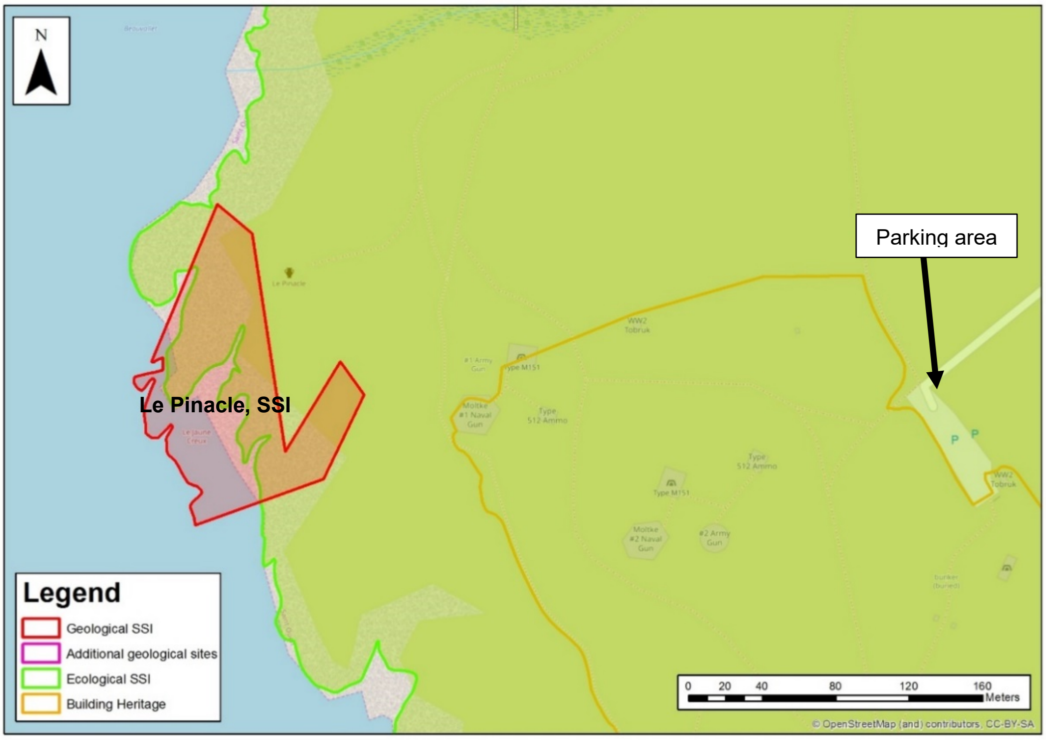


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.9 SITE NAME: LE PINACLE (THE PINNACLE), SSI

Site Information:	
The site is a section of dramatic cliff-lined coast near the north end of the west coast of Jersey that includes The Pinnacle (also known as Le Pinacle), a large and visually striking 'fossil stack'. This well-known geomorphological structure is the main feature of interest, but the site includes good outcrops of *St Mary's granite* (the largest component of the *North-west igneous complex*), perhaps the best examples in Jersey of igneous sills, good examples of wave-cut notches formed in the geologically recent past when the relative sea level was higher than it is now and some important prehistoric structures. A significant sequence of Quaternary head lies preserved on the landward side of Le Pinacle; it preserves significant prehistoric and Romano-Gallic archaeology at the surface as well as prehistoric artefacts within the deeper sediments themselves.	
National Grid Reference: Mid-point: 31401, 72464 West end: 31348, 72463 East end: 31476, 72451	**Site Type:** Natural exposure
Site Ownership: To be confirmed	**Current Use:** Open country
Field Surveyors: M Gillespie and R Kendall	**Current Geological Designations:** Geological SSI
Date Visited: 18 October 2019	**Other Known Designations:** The site area coincides with part of an Ecological SSI (Les Landes) and part of a Building Heritage site (Les Landes Prehistoric Landscape). The site also sits within Jersey National Park.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:

Age: Ordovician Period	**Formation:** *North-west igneous complex* (St Mary's granite)
Rock Types: Granite	
Age: Not known	**Formation:** Unnamed sills
Rock Types: Basalt and/or dolerite	
Age: Quaternary	**Formation:** Unnamed deposit
Rock Types: Head (poorly sorted, weakly stratified and unlithified diamicton containing angular blocks of local bedrock)	

Site Description:

Introduction

This easily accessed and visually impressive site presents a range of geomorphological, geological and archaeological features. The main feature of interest is The Pinnacle (also known as Le Pinacle), a large, striking, fin-shaped 'fossil stack' that is one of the best-known geomorphological structures in Jersey (Photos 1 and 2). The long axis of the 'fin' trends NNE–SSW, and the north-north-east end is connected to the mainland by a narrow, grassy col. Underlying the col is a deep, narrow gully that effectively separates the bedrock forming The Pinnacle from bedrock forming the mainland; the gully is currently filled with head, which has been eroded by both the current and the MIS 5 sea level (Photo 2). There is also an 18 m wave-cut notch halfway up the head infilling the gully.

The bedrock throughout the site is predominantly *St Mary's granite* of the *North-west igneous complex*, but gently dipping sheets of dark grey dolerite cut the granite in places. Wave-cut notches in the sea cliffs beside The Pinnacle attest to how the relative sea level has changed in the geologically recent past in response to global cooling and warming. The site includes archaeological structures in which evidence has been found for occupation spanning from the Neolithic to Gallo-Roman times. Dolerite from the sill exposed here was used by Neolithic peoples to create stone tools, which were exported to or trained into Guernsey (information from J Renouf).

Bedrock Units

North-west igneous complex

The *North-west igneous complex* is one of three major intrusion complexes in Jersey. Two main components of the *North-west igneous complex* were distinguished on the geological map of Jersey (IGS, 1982): *St Mary's granite*, which forms more than 90% of the onshore outcrop, and *Mont Mado granite*, which underlies a sliver of ground at the eastern extremity of the outcrop. Subsequently, the outcrop of *St Mary's granite* has been divided into several components distinguished by their textural and/or mineralogical characteristics. These components are distributed in a concentric or 'bullseye' pattern (Figure 3): there is an outer zone of 'coarse granite', a middle zone of 'porphyritic granite' and a small central zone of 'biotite microgranite' (Bland, 1985; Brown *et al*., 1990). This pattern suggests that the *North-west igneous complex* is a single concentrically zoned pluton. Most of the pluton is of granite composition, but bodies of 100 m to 1 km scale made of diorite, gabbro, and lithologically heterogeneous rocks, which formed through the mingling of basic and siliceous magmas, crop out discontinuously within a swathe of ground roughly 2 km wide that extends from St John's Village to the coast around Sorel Point. Extensive outcrops along the north-west coast of Jersey present excellent examples of all the main components of the *North-west igneous complex*.

The geometry of the bullseye pattern suggests that most of the outcrop of the *North-west igneous complex* is on mainland Jersey, with only about one quarter of the pluton lying offshore. On this basis, the outcrop of the whole pluton would be around 10 x 6 km. However, granitic rocks crop out on the seafloor for a considerable distance to the north and west of north-west Jersey (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the north of the *North-west igneous complex* (Figure 7).

A U-Pb zircon age of *c.* 483 Ma for a sample of *St Mary's granite* from Mont Huelin Quarry (Miller *et al.,* 2001), in the outermost zone of the pluton, confirms that the *North-west igneous complex* was emplaced in the Ordovician Period. As such, it is around 100 million years younger than the other two main igneous complexes in Jersey (*South-west igneous complex* and *South-east igneous complex*), and it is not related to them or to the Cadomian Orogeny. The cause of the magmatism that produced the *North-west igneous complex* is not clear, but it may have been a late Cadomian event or it may have been linked to widespread tectonic events around the Iapetus and Rheic ocean realm at this time.

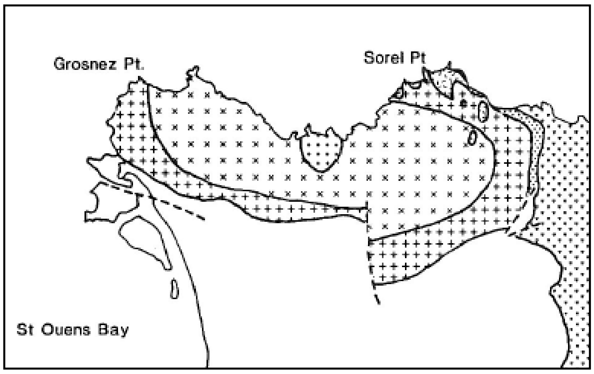


Figure 1. Concentric zoning in the *North-west igneous complex*. Adapted from figure 19 in Brown *et al.* (1990).

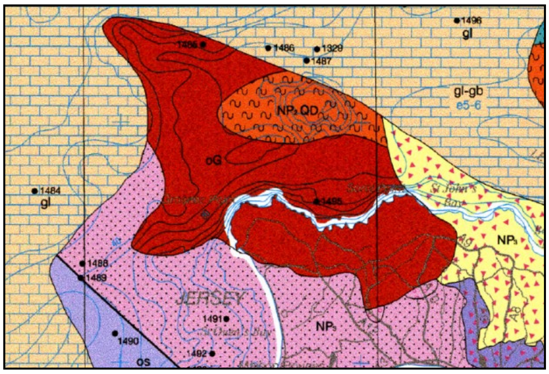


Figure 2. Map of onshore and offshore bedrock geology around north-west Jersey (coastline in white) showing the apparent offshore continuation of the *North-west igneous complex*. From BGS (2000).

Bedrock Features

The bedrock underlying the site consists almost entirely of *St Mary's granite*, which is the main component of the *North-west igneous complex*. The granite consists of roughly equal proportions of orange to pink alkali feldspar, white plagioclase feldspar and grey quartz, with a small proportion of dark biotite mica (Photo 3). Sheets of pink microgranite (sometimes called felsite or aplite) and gently dipping veins of white quartz (Photo 4) cut the granite locally; the microgranite sheets probably formed as a late-stage product of the magmatism that produced the *St Mary's granite*, while the quartz veins probably formed from hot (hydrothermal) fluid that circulated through the cooling rock mass.

The granite forming The Pinnacle is cut by a gently inclined sheet, or sill, of dark grey rock (probably dolerite) at approximately the level of the top of the head-filled gully (Photos 5 and 6). The sill is around 1 m thick and dips gently toward the south-east. Several other sills, most of which are thinner but otherwise have a similar character and orientation, are exposed in the cliffs south and north of The Pinnacle; some of these sills can be seen from the cliff path. These may be the best examples of sills (and a sill swarm) in Jersey. The sills have not been dated, but they are clearly younger than the *St Mary's granite* and were emplaced in a very different tectonic regime; as such, they are probably associated with a geological event that is younger than, and unrelated to, the event that produced the *North-west igneous complex*.

Geomorphology

The site presents a good opportunity to see how erosion exploits weak zones in bedrock to produce geomorphological features at all scales, including this impressive coastal stack.

The features that have the most influence on bedrock weathering and erosion in this locality (and many others) are unmineralised fractures known as joints. In this part of Jersey, joints formed as the land was uplifted and eroded in the geologically recent past, a process that brought buried granite towards the ground surface. As it approached the surface, the rock expanded slightly, causing numerous cracks (i.e., joints) to form in the brittle material. Once formed, the joints represented natural lines of weakness in the rock, and they have been exploited by weathering and erosion to form the complex cliffs and crags, and the numerous gullies, that characterise the landscape we see today (Photos 1 and 2). Many of the largest joints in the bedrock around The Pinnacle are subvertical and form sets of near-parallel features; the most prominent set in the outcrop trends roughly NNE–SSW. The Pinnacle, whose long axis also trends NNE–SSW, is bounded on its north-west and south-east sides by two of these prominent joints (see the 'Map of the site boundary on an aerial photograph' towards the end of this site description); this spatial relationship demonstrates clearly that these joints have exerted significant influence over the position, shape and orientation of The Pinnacle by controlling where it is easiest for waves to penetrate and shape the coastal cliffs. The head-filled gully at the north-north-east end of The Pinnacle probably belongs to another set of large subvertical joints that trend NW–SE.

The very steep north-west (seaward) face of The Pinnacle presents a further example of how erosion has exploited structural weakness in the bedrock, in this case due to contrasting rock properties. Here, the dolerite sill near the base of the stack has eroded faster than the enclosing granite, effectively undercutting the overlying granite, which has therefore eroded faster than the granite below the sill. The result is a projecting shelf of granite (essentially the footwall surface of the sill) at the level of the sill, and an unusually steep face above the sill (Photo 5). The site also presents several features that demonstrate how the relative sea level has fluctuated in the geologically recent past in response to global cooling and warming events (i.e., during cold and warm stages). Current evidence suggests that the stack originally formed at least 200,000 years ago; since this time, the relative sea level has risen and fallen several times in association with warm and cold stages, respectively. The gully underlying the col at the north-north-east end of The Pinnacle has been alternately filled with head and re-exhumed during these events. The available evidence indicates that the gully was deepened, more or less to its present limit, during the last warm stage (the Ipswichian), but it was then filled with head during the 100,000 or so years of the last cold stage (the Devensian). Much of that head (Photo 7) has eroded in the last 1,000 years, and the same erosive forces have produced a 'cave' that cuts through the head and connects the north and south sides of the col near the top of the gully. A wave-cut notch on the east side of the gully represents the position of the '18 m' raised beach in Jersey; below this point, further wave-cut notches at about the current high-water mark represent the position of the '8 m' raised beach.

It is interesting to note that one of the earliest accounts of this area was published by Charles Noury in 1886: he predicted that The Pinnacle would collapse within the following hundred years.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	A dirt track heading west from the B55 where Route du L'Ouest meets Rue de la Mare leads to a parking area.
Access	A worn footpath of around 300 m leads from the parking area to the clifftop trail from which the various features at this site can be observed. A pathless, grassy slope must be descended to reach the base of The Pinnacle and the adjacent archaeological features.
Safety of access	The clifftop footpaths are generally safe, but signage is limited and there is the potential to get lost if the visibility is poor. The ground to the west of the clifftop path is steep, rugged, exposed and dangerous in places. Access from the south along the shore depends on the tide.
Safety of exposure(s)	The Pinnacle consists of steep rock and should be viewed from a distance. The shelf beneath the dolerite sill on the north and north-north-west flanks of The Pinnacle can be accessed with care from the col.
Current condition	The bedrock and Quaternary deposits (head) are weathered but in generally good condition.
Current conflicting activities	None
Restricting conditions	None
Nature of exposure(s)	The Pinnacle is a large sea stack; nearby exposures (on the mainland) include coastal cliffs and rocky outcrops.

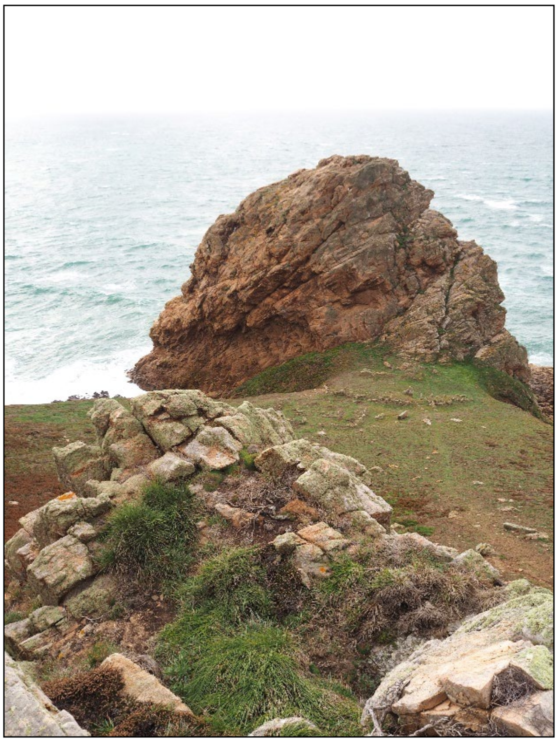
Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Le Pinacle is a complex multi-period site positioned below an imposing North-west granite fossil stack, which is separated from the land by a deep marine-eroded gully partly filled by head from the last cold stage (HER Number 0900343; Listed place OU175). Le Canal du Squez produced the largest Mesolithic assemblage from the Channel Islands (Patton, 1993; HER Number 0900348; Listed place OU175). Les Landes Area of Prehistoric Activity is an important prehistoric landscape with archaeological sites from the Palaeolithic, Mesolithic and Neolithic. It is of outstanding importance to the archaeological heritage of Jersey and includes evidence of importance to European prehistory (HER Number 0900175; Listed place OU175). Battery Moltke was part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall (HER Number 0900091; Listed building OU0091). Also see the next page.
Aesthetic landscape	The Pinnacle is an impressive geomorphological feature, and generally the site is in an impressive and aesthetically pleasing coastal setting.
History of Earth science	Not known
Economic geology	None

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Local	Good	Descriptions	
Structural geology				
Palaeontology				
Geomorphology	Local	Good	Descriptions	X

Geoscientific Value of the Site
This easily accessible and visually impressive site presents a range of geomorphological, geological and archaeological features. The main feature of interest is The Pinnacle (also known as Le Pinacle), a large and visually striking 'fossil stack' that is one of the best-known geomorphological structures in Jersey. The site presents a good opportunity to see how features that introduce structural weakness to a rock mass (in this case, joints and sills) control how geomorphological features (such as this coastal stack) evolve. The bedrock throughout the site is *St Mary's granite* of the *North-west igneous complex*, but gently dipping sheets of dark grey dolerite cut the granite in places and may be entirely unrelated to it. Wave-cut notches and a head-filled gully attest to how the relative sea level has changed in the geologically recent past in response to global cooling and warming. Wave-cut notches can be seen in other parts of Jersey, but those at The Pinnacle are said to provide the easiest access for visiting groups. The site includes archaeological structures in which evidence has been found for occupation spanning from the Neolithic to Gallo-Roman times.

Assessment of Site: Current Site Usage	
Community	The site is a popular place for locals to go walking.
Education	The site is often used by school groups, and possibly other groups, studying physical geography, geology and archaeology.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust. Exposures of head are generally inaccessible, and therefore protected, but access paths are vulnerable to erosion.
Potential use	As a well-known geomorphological feature, The Pinnacle already draws visitors, making this a good place to introduce geological concepts to the general public. This could be done using geotrails, leaflets or interpretation boards. In addition to the fossil stack, the site includes good outcrops of St Mary's granite and some of the best views of igneous sills, as well as good examples of wave-cut notches formed in the geologically recent past, when the relative sea level was higher than it is now, and some important prehistoric structures. All of this makes it a good place for research and education.

Site Photos:	
 **Photo 1:** The Pinnacle viewed from coastal cliffs around 300 m to the north. The main face in view is the very steep north-west (seaward) face of the stack, and the low, grassy ground to the left of the summit is the col overlying a head-filled gully at its north-north-east end. In the foreground is the top surface of a strongly eroded granite boulder. BGS © UKRI 2020.	 **Photo 2:** The Pinnacle viewed from the east. The grassy platform is the col overlying a head-filled gully; on this platform, the remains of a rectangular Gallo-Roman temple can be seen. The pale band of rock heading from the col towards the right edge of the stack is a shelf of granite underlying an eroded dolerite dyke. BGS © UKRI 2020.
 **Photo 3:** Typical St Mary's granite on a weathered surface near The Pinnacle. Alkali feldspar is pale orange, plagioclase feldspar is cream and quartz is grey; the rock contains a small proportion of dark biotite mica, which is difficult to see on weathered surfaces. Pen for scale. BGS © UKRI 2020.	 **Photo 4:** A vein of white quartz cutting a sheet of pink microgranite (or 'aplite'), which in turn cuts weathered St Mary's granite in a boulder near The Pinnacle. Pen for scale. BGS © UKRI 2020.

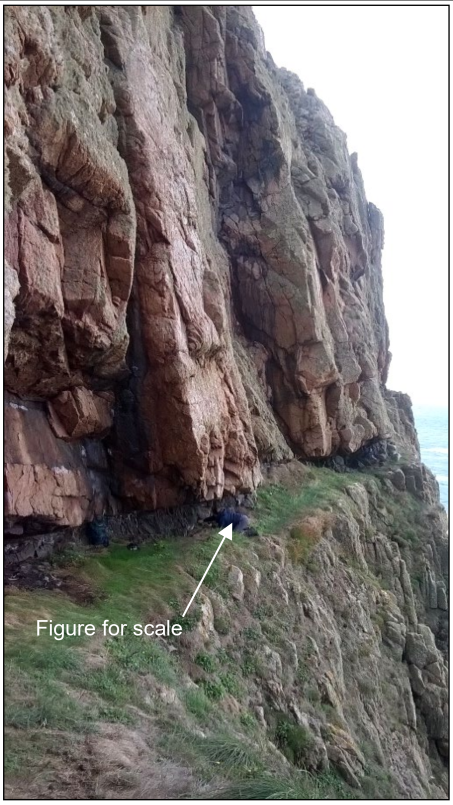
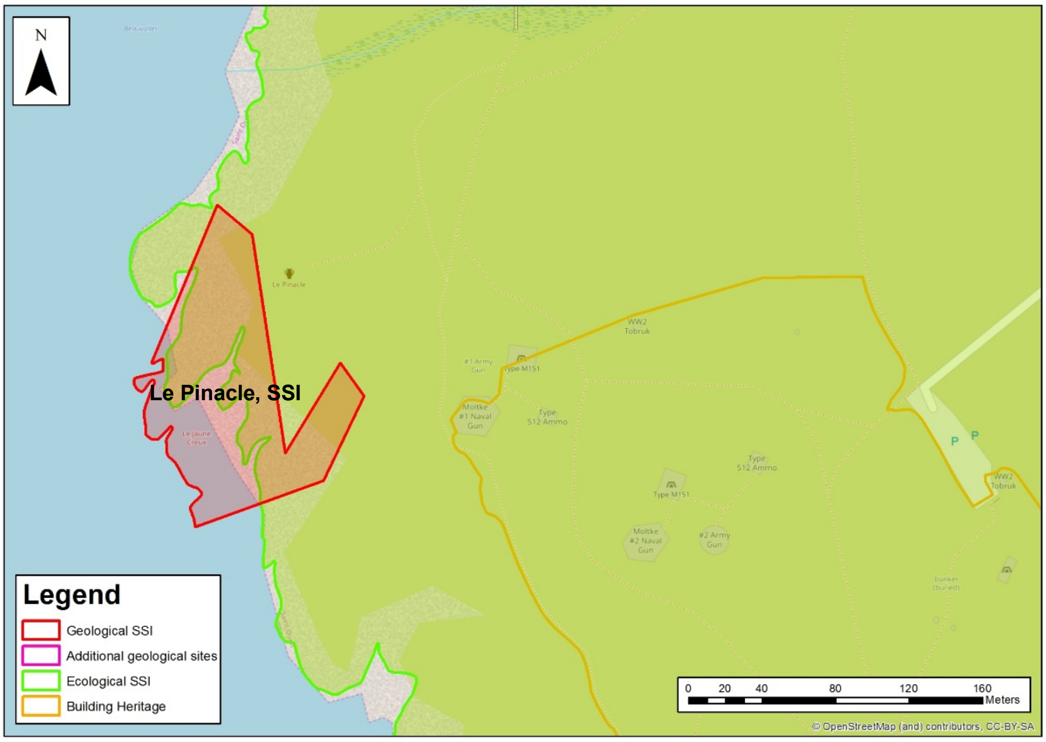


Photo 5: Looking south-west along the narrow shelf formed on the lower (footwall) surface of a dolerite sill (dark grey), which has eroded faster than the surrounding granite, causing it to become recessed and thereby undermine the overlying granite. Fresh, pink surfaces in the granite above the dyke have been revealed by recent erosion, while weathered grey surfaces in the granite below the dyke indicate that there has been relatively little erosion there. The kneeling figure is examining the dyke. BGS © UKRI 2020.

Photo 6: Close-up of the recessed dolerite sill shown in Photo 5. Hammer for scale. BGS © UKRI 2020.

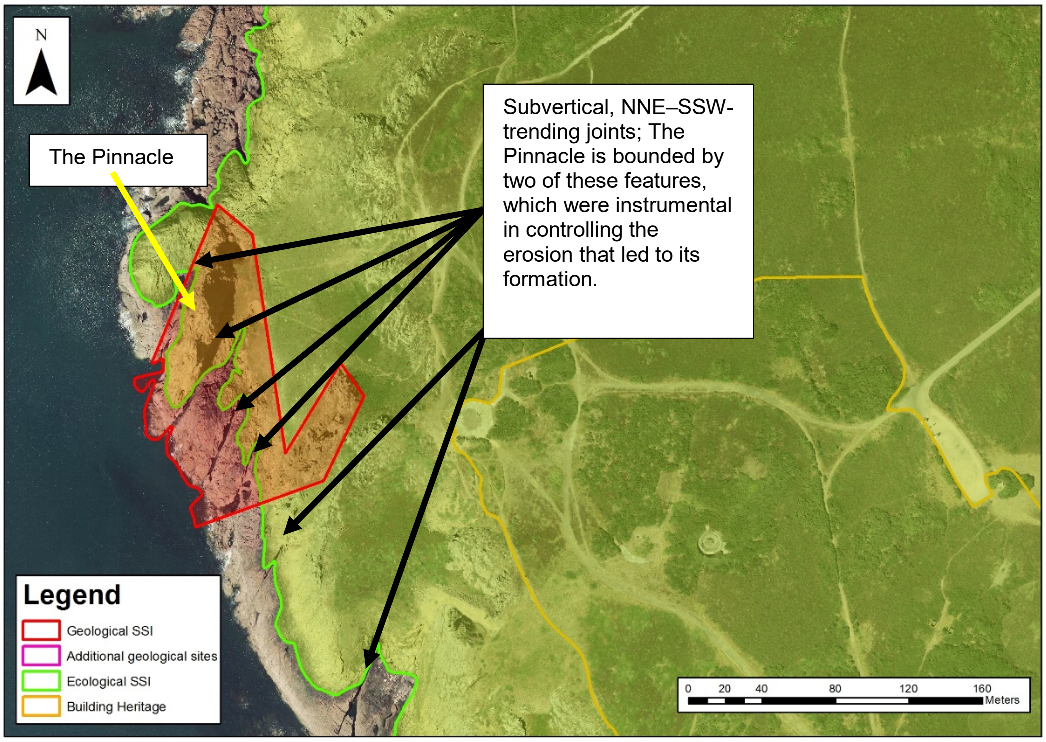
Photo 7: Looking south from the col beside the north-north-east end of The Pinnacle across an exposure of orange head filling a gully beneath the col. In the distance is a coastal cliff of St Mary's granite within which a near-horizontal dark line marks the position of a dolerite sill. The exposure of head is around 4 m high. BGS © UKRI 2020.

Map of the site boundary on a topographic base



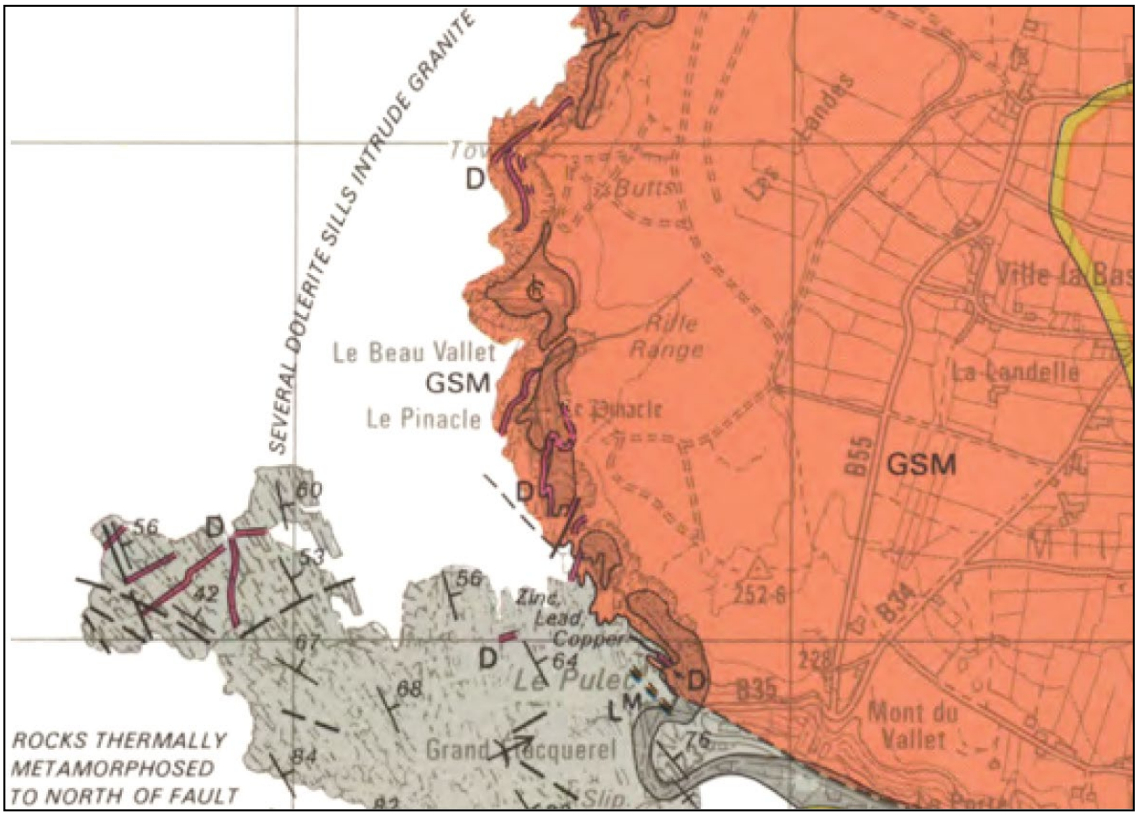
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

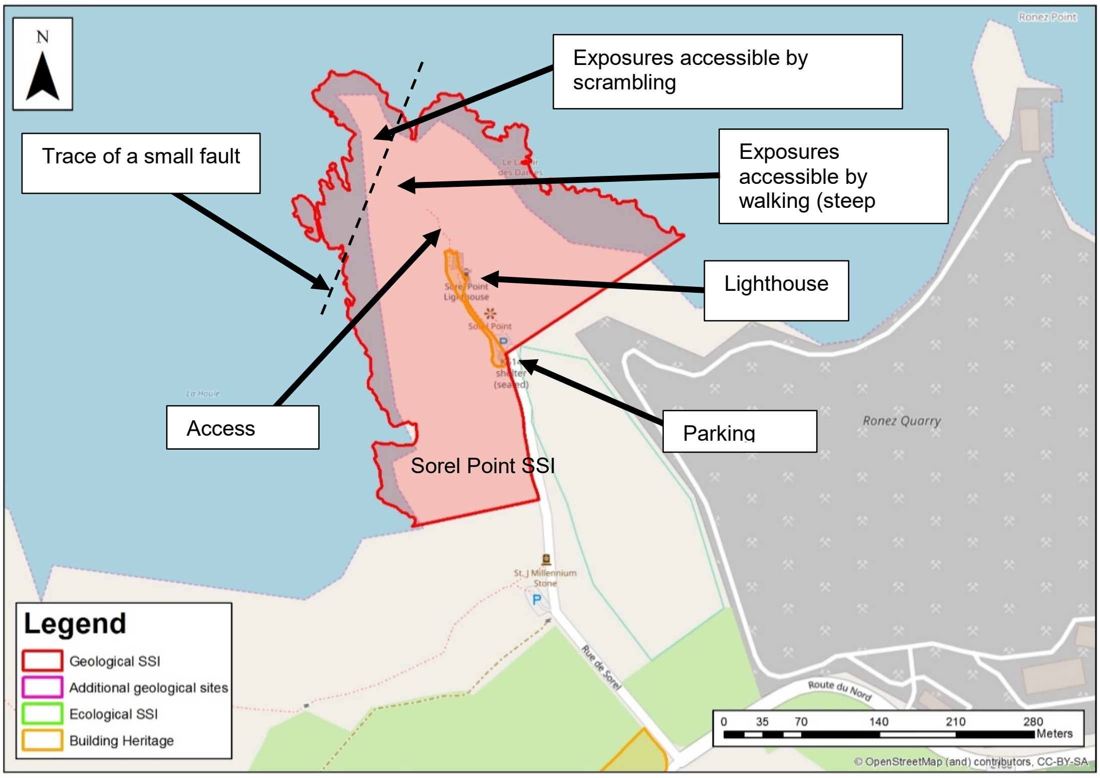


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.10 SITE NAME: SOREL POINT, SSI

Site Information:	
Sorel Point is a steep, craggy headland on the north coast of Jersey where a lithologically diverse part of the *North-west igneous complex* is exposed. The site provides a window into the processes and lithological associations that can occur in dynamic magma chambers, and it has a long association with the development of ideas about how coeval magmas interact and evolve; it therefore is arguably of international importance. However, scrambling on steep, rocky ground is required to reach many of the best exposures.	
National Grid Reference: Mid-point: 38266, 73929 West end: 38102, 73963 East end: 38454, 73934	**Site Type:** Natural exposure
Site Ownership: Public	**Current Use:** Open country, coastal
Field Surveyors: M Gillespie and R Kendall	**Current Geological Designations:** Geological SSI
Date Visited: 14 October 2019	**Other Known Designations:** The site encompasses a Building Heritage site (German Occupation Site: Army Coastal Observation Post M4 & Lighthouse). The site also sits within Jersey National Park.

Site Map



Stratigraphy and Rock Types:	
Age: Ordovician Period	**Formation:** *North-west igneous complex*
Rock Types: Granite, granodiorite, diorite and gabbro	

Site Description:

Introduction

The north-east corner of the *North-west igneous complex* is lithologically more diverse than other parts due to the presence of large bodies of diorite and gabbro as well as the more typical granitic rocks. At Sorel Point, a broad spectrum of igneous lithologies – including gabbro, diorite, granodiorite and granite – is exposed, and the bedrock here preserves evidence of a prolonged and complex history of magma emplacement and interactions. The most accessible part of the site – the spine of the headland – is underlain by several visually distinct lithologies, including dark grey diorite, coarse grey granodiorite and pink granite. The stark visual contrast between these lithologies allows the contacts between them to be traced easily in the well-exposed bedrock; as such, the temporal relationships of the magmas, and a range of features produced by their physical interactions, can be examined in detail.

The recognition that magma chambers can be highly dynamic settings and that the interaction (by mingling and mixing) of co-existing compositionally diverse magmas is an important driver of compositional evolution in igneous rocks have been key discoveries in the field of igneous petrology. Unsurprisingly, Sorel Point has a long association with the development of such ideas, starting with Parkinson (1899), who proposed a then 'somewhat revolutionary' but insightful hypothesis that rocks of intermediate composition may arise from the interaction of basic and siliceous magmas. Subsequent authors, including Wells and Wooldridge (1931), Wells and Bishop (1955) and Bishop (1963), presented varying interpretations of the Sorel Point rocks that were influenced by, and in line with, contemporaneous thinking. More recently, a forensic study by Salmon (1987, 1991, 1992, 1996, 1998) revealed in considerable detail the complex, multistage history of magmatism at Sorel Point and the extent to which compositionally contrasting magmas had co-existed and interacted during the different stages.

Bedrock Units

North-west igneous complex

The *North-west igneous complex* is one of three major intrusion complexes in Jersey. Two main components of the *North-west igneous complex* were distinguished on the geological map of Jersey (IGS, 1982): *St Mary's granite*, which forms more than 90% of the onshore outcrop, and *Mont Mado granite*, which underlies a sliver of ground at the eastern extremity of the outcrop. Subsequently, the outcrop of *St Mary's granite* has been divided into several components distinguished by their textural and/or mineralogical characteristics. These components are distributed in a concentric or 'bullseye' pattern (Figure 3): there is an outer zone of 'coarse granite', a middle zone of 'porphyritic granite' and a small central zone of 'biotite microgranite' (Bland, 1985; Brown *et al*., 1990). This pattern suggests that the *North-west igneous complex* is a single concentrically zoned pluton. Most of the pluton is of granite composition, but bodies of 100 m to 1 km scale made of diorite, gabbro, and lithologically heterogeneous rocks, which formed through the mingling of basic and siliceous magmas, crop out discontinuously within a swathe of ground roughly 2 km wide that extends from St John's Village to the coast around Sorel Point. Extensive outcrops along the north-west coast of Jersey present excellent examples of all the main components of the *North-west igneous complex*.

The geometry of the bullseye pattern suggests that most of the outcrop of the *North-west igneous complex* is on mainland Jersey, with only about one quarter of the pluton lying offshore. On this basis, the outcrop of the whole pluton would be around 10 x 6 km. However, granitic rocks crop out on the seafloor for a considerable distance to the north and west of north-west Jersey (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the north of the *North-west igneous complex* (Figure 7).

A U-Pb zircon age of *c.* 483 Ma for a sample of *St Mary's granite* from Mont Huelin Quarry (Miller *et al.,* 2001), in the outermost zone of the pluton, confirms that the *North-west igneous complex* was emplaced in the Ordovician Period. As such, it is around 100 million years younger than the other two main igneous complexes in Jersey (*South-west igneous complex* and *South-east igneous complex*), and it is not related to them or to the Cadomian Orogeny. The cause of the magmatism that produced the *North-west igneous complex* is not clear, but it may have been a late Cadomian event or it may have been linked to widespread tectonic events around the Iapetus and Rheic ocean realm at this time.

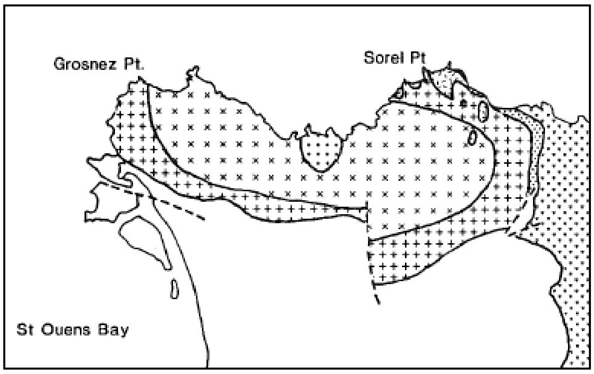


Figure 1. Concentric zoning in the *North-west igneous complex*. Adapted from figure 19 in Brown *et al.* (1990).

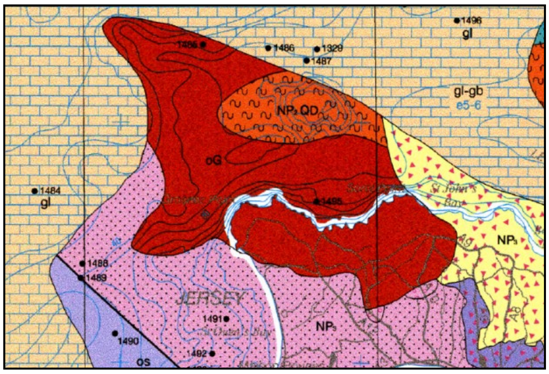


Figure 2. Map of onshore and offshore bedrock geology around north-west Jersey (coastline in white) showing the apparent offshore continuation of the *North-west igneous complex*. From BGS (2000).

Bedrock Features

The following captures only some of the detail of this geologically very complex site; readers should refer to Salmon (1998) for both a detailed account and maps showing the distribution of lithologies.

Based on detailed mapping, Salmon (1987, 1991, 1992, 1996, 1998) concluded that the intrusive rocks of Sorel Point can be divided into four 'groups', each representing a distinct episode of intrusion; observations in Ronez Quarry, which lies immediately east of the site, suggest that additional intrusive episodes can be recognised there. Salmon was able to place the groups in chronological order and show that each one is separated from the others by sharp, angular contacts; thus, the rocks forming each group had crystallised fully before the magmas of the succeeding group were emplaced. Salmon labelled the groups with letters from A to D, with A being the earliest group. Group A, which underlies the north and east parts of the headland (including nearly all of the Sorel Point site), includes pink 'aplogranite'[3], grey granodiorite and dark grey diorite and gabbro. Group B, which crops out mainly on the west side of the headland, is dominantly gabbro and subordinate diorite. Group C, which crops out only in the south-west corner of the site and is by far the least extensive of the four, is mainly diorite. Finally, Group D consists of coarse granite in large, subvertical, NNW–SSE-trending sheet-like intrusions and smaller offshoots, which cut across the earlier groups. Groups A, B and C include at least two lithologies that were present as co-existing magmas.

Salmon did not link any of the lithologies he described to units recognised elsewhere in the *North-west igneous complex*, but on the geological map of Jersey (IGS, 1982), the outcrop of

[3] Salmon described this as aplogranite; however, crystals are clearly visible to the unaided eye and microgranite may be a more appropriate term.

Group A aplogranite is identified as *Mont Mado granite* and the outcrop of Group 4 granite is classified as *St Mary's granite*.

The steep and rugged terrain at Sorel Point means that most of the exposures are on relatively inaccessible ground that lacks paths and requires considerable care to access safely. However, a (poorly maintained and rather rough) footpath descending northwards from the parking area towards the headland provides access to arguably the best and most interesting exposures in the site. The footpath ends at a point where a small NNE–SSW-trending fault cuts through the headland (see the Site Map above), and progress beyond this point towards the tip of the headland requires some mild scrambling and the use of hands. All of the rock exposed between the parking area and the northernmost tip of Sorel Point belongs to Group A and Group D; the key lithologies in these groups, and a wide range of the important textural features, can be examined in this part of the site.

Salmon (1998) used the present moderately dipping orientation of layered rocks at Sorel Point (which he assumed were horizontal originally) and pipe-like intrusions (assumed to be vertical originally) to infer that, once it had solidified, the block of Group A rocks rotated downwards into another magma chamber (now Group B rocks), such that the Group A block is now tilted southwards at around 45–50^0. Thus, a traverse from south to north across the outcrop in this northern part of the Sorel Point site presents rocks that represent progressively deeper parts of the magma chamber in which the Group A rocks formed: a body of strikingly pink 'aplogranite' forms the northern end of the outcrop (i.e., the deepest part of the magma chamber); moving south, the pink aplogranite passes up into mafic rocks – initially diorite, then hornblende gabbro and finally layered gabbro (Photo 1).

A direct contact between the aplogranite and diorite is visible locally, but in most places the contact has been 'invaded' by coarse grey granodiorite, which forms a discontinuous 'screen' up to 3 m wide separating the two larger masses (Photo 2). Offshoots of granodiorite from the screen take a range of forms, including tabular sheets, irregular veins and cylindrical pipes. A wealth of superbly exposed evidence, including gradational contacts and textures produced by magma mingling and mixing, indicates that these three visually very different rocks formed from co-existing magmas (Photos 3–8).

Ovoid patches of pegmatitic diorite are developed locally within the Group D diorite; a steep, 3-m-high, west-facing exposure some 20 m south-south-west of the point where the path reaches the small fault presents a cluster of these features (Photos 9–11).

Higher up on the spine of the headland, the path passes a large outcrop on the ridge crest in which clean exposures of homogeneous, dark grey Group A hornblende gabbro can be examined (Photo 12). The rock here is mainly homogeneous, lacking the layered character of gabbros a little further to the south and the mingling textures that are common in dioritic rocks a little further to the north.

The Group D granite is coarse-grained and has abundant tabular crystals of alkali feldspar, which is often orange; a weak subvertical alignment of the feldspar crystals in some exposures is probably a pre-full crystallisation (PFC) fabric created when the magma flowed or was compressed (Photo 13). Ferromagnesian minerals in the granite include hornblende as well as biotite. Occasionally, the granite encloses partly rounded fragments of diorite and gabbro, which are probably xenoliths that were entrained as the magma passed through the local Group A country rocks (Photo 14). The contact with Group A aplogranite can be examined near the northern tip of Sorel Point, though scrambling is required to reach the area; the contact is sharp but marked by a band of yellowish rock, which may be a chilled margin in the Group D granite (Photo 15).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	A public road provides access to a small parking area near the lighthouse.
Access	Most of the site consists of relatively inaccessible ground that lacks paths and requires considerable care to access safely. However, a poorly maintained and rather rough footpath descends northwards from the parking area towards the headland and provides access to an area containing arguably the best and most interesting exposures in the site. The footpath ends at a point where a small NNE–SSW-trending fault cuts through the headland (see the Site Map above), and progress beyond this point towards the tip of the headland requires mild scrambling and the use of hands.
Safety of access	Most of the site consists of relatively inaccessible ground that lacks paths and requires considerable care to access safely. A path descending northwards from the parking area towards the tip of Sorel Point is rough and steep in places but provides reasonably safe access to some good exposures. Progress beyond the path into an area containing arguably the best and most interesting exposures in the site requires mild scrambling and the use of hands.
Safety of exposure(s)	The best and most interesting exposures in the site consist of large rocky pinnacles and platforms situated on a wild, exposed headland; care is required to reach this area and to move about safely within it.
Current condition	The bedrock exposures are in generally good condition.
Current conflicting activities	None
Restricting conditions	Exposures near the northern tip of Sorel Point are either close to or within the intertidal zone and so they are subject to tides.
Nature of exposure(s)	The exposures are mainly craggy cliffs and outcrops on a steep slope.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	The site encompasses a Building Heritage site from the German Occupation. Resistance Nest Sorel B is part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall (HER Number 0500077; Listed building JN0077). Flint bevelender found at Sorel Point (0500270).
Aesthetic landscape	Sorel Point is a wild, rocky, visually impressive headland with extensive views north, east and west.
History of Earth science	Sorel Point has a long association with the development of important ideas in igneous petrology, starting in 1899. See the main text for further details.
Economic geology	None

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	International	Excellent	Detailed studies	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site
Sorel Point is one of the best places in Jersey to see evidence of how co-existing but compositionally distinct magmas interact in a dynamically evolving magma chamber. The site has a long association with the development of ideas about how coeval magmas interact and evolve and is arguably of international importance.

Assessment of Site: Current Site Usage	
Community	The site lacks good paths and visitor facilities, and as such it is probably infrequently used by members of the wider local community other than dog walkers, local fisherman, bird watchers and the riders that use the motocross track on the headland.
Education	Not known

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust, but the path is vulnerable to erosion.
Potential use	Sorel Point is an exceptional site for studying a lithologically diverse part of the North-west igneous province. This site provides a window into the processes that occur in dynamic magma chambers. The site is arguably of most use to researchers and higher education parties, as much of this site is only accessible by scrambling and should only be accessed with care. The site could benefit from leaflets or interpretation boards and be part of geotrails, but they should focus on the interpretation of the features visible from the top of the cliff.

Site Photos:

Photo 1: Looking north-west towards the headland at Sorel Point from the path a short distance below the lighthouse. Most of the outcrop in this view consists of Group A rocks, which form a block dipping south (towards the photographer) at a moderate angle. In general, therefore, exposures further from the photographer in this view were deeper in the magma chamber before the block was tilted. Pink aplogranite forming the far headland passes up into diorite (dark pinnacle in front of the microgranite) and then hornblende gabbro (grey rock left of centre in the middle distance). This in turn passes up into layered gabbro, which underlies the ground out of view to the left. Foreground exposures are made of Group D granite, which here forms a NNW–SSE-trending sheet cutting the Group A rocks. A band of brown rocks towards the left side of the pink aplogranite outcrop is also Group D granite, probably a continuation of the sheet underlying the foreground exposures. The distance to the tip of the headland is around 200 m. BGS © UKRI 2020.

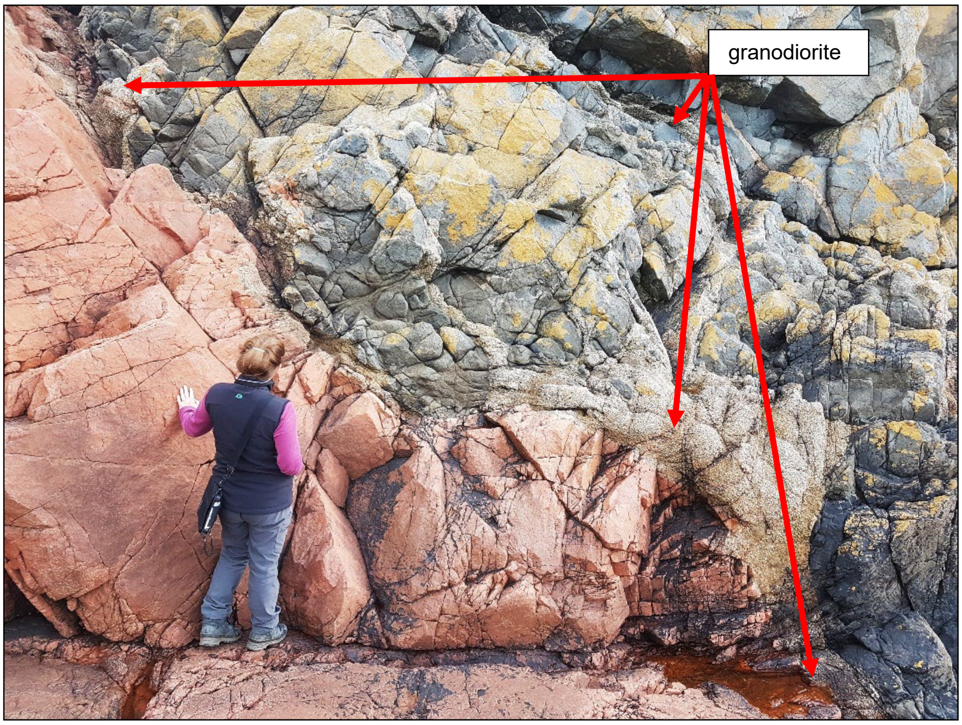


Photo 2: Looking south towards the contact zone between pink aplogranite and grey diorite near the northernmost part of the outcrop at Sorel Point. Coarse, pale grey granodiorite (arrowed) forms a narrow 'screen' between the aplogranite and diorite, and irregular offshoots that 'invade' the diorite. All lithologies are part of Group A. Figure for scale. BGS © UKRI 2020.

Photo 3: A typical contact between pink aplogranite and grey, coarse granodiorite (both Group A) in the contact zone shown in Photo 2. The aplogranite has an obvious chilled margin (roughly spanning the zone indicated by the black line), but the irregular and partly interdigitated boundary indicates that neither magma was fully solidified when they came into contact. Pen for scale. BGS © UKRI 2020.

Photo 4: A contact between grey, coarse granodiorite and dark grey diorite (both Group A) in an exposure towards the north end of Sorel Point. The two rocks are intimately associated within a broad, gradational contact zone (in which they could be said to be thoroughly mingled or incompletely mixed), indicating that they crystallised from co-existing magmas. Pen for scale. BGS © UKRI 2020.

Photo 5: A large exposure of dark grey diorite and pale grey, coarse granodiorite towards the north end of Sorel Point (a few metres above the area shown in Photo 2). The now-weathered granodiorite is distributed irregularly within the diorite, and contacts between the two are convoluted and often lobate, indicating that they crystallised from co-existing magmas. The field of view is roughly 4 m from top to bottom. BGS © UKRI 2020.

Photo 6: A vertical section through a typical granodiorite 'pipe' in an exposure towards the north end of Sorel Point. The pale grey, coarse granodiorite and dark grey diorite (or gabbro) host are both Group A. The pipe is cylindrical and slightly sinuous. Granodiorite in the lower half of the pipe has weathered out. Pen for scale. BGS © UKRI 2020.

Photo 7: A broad, gradational contact between pale, coarse granodiorite and dark grey diorite (both Group A) in an exposure towards the north end of Sorel Point. Larger 'enclaves' of diorite in the granodiorite suggest that the diorite was partly solidified when the two lithologies came into contact, but the intimate (thoroughly mingled) manner in which they are associated indicates that both were essentially in a magmatic state. Pen for scale. BGS © UKRI 2020.

Photo 8: Close-up of a contact between pale, coarse granodiorite and dark grey diorite (both Group A) in an exposure towards the north end of Sorel Point. The 'lobate' nature of the main contact, and the presence of rounded 'fragments' of diorite in the granodiorite (beneath the pen) and vice versa (at right), indicate that the two rocks crystallised from co-existing magmas. Pen for scale. BGS © UKRI 2020.

Photo 9: A patch of pegmatitic diorite, formed of coarse white plagioclase feldspar and black hornblende, in an exposure of diorite towards the north end of Sorel Point**.** Pen for scale. BGS © UKRI 2020.

Photo 10: A patch of pegmatitic diorite, formed of coarse white plagioclase feldspar and black hornblende, in an exposure of diorite towards the north end of Sorel Point**.** Pen for scale. BGS © UKRI 2020.

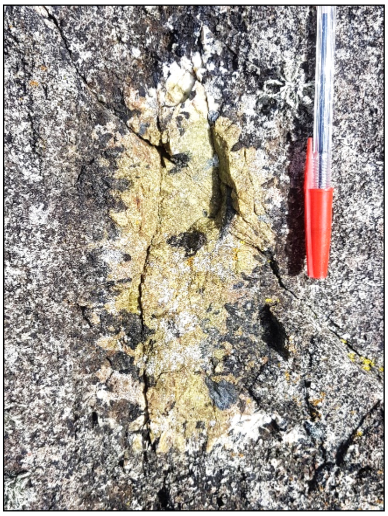


Photo 11: A patch of pegmatitic diorite, formed of coarse white plagioclase feldspar, black hornblende and yellowish epidote, in an exposure of diorite towards the north end of Sorel Point**.** Pen for scale. BGS © UKRI 2020.

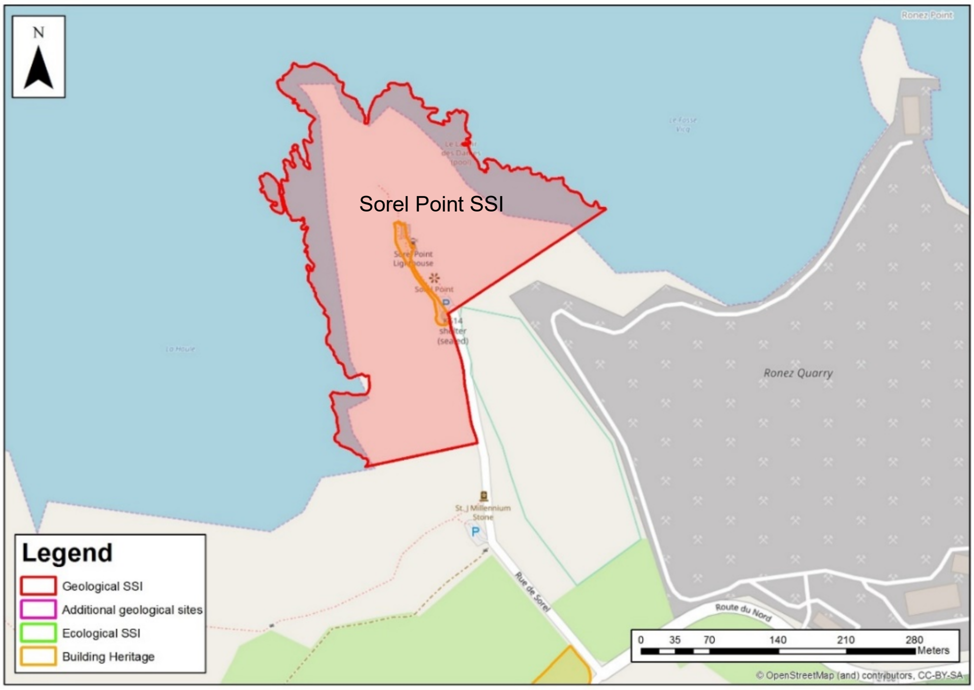
Photo 12: Dark grey Group A hornblende gabbro forming part of the hornblende gabbro exposure shown in Photo 1. The rock here is mainly homogeneous, lacking the layered character of gabbros a little further to the south and the mingling textures that are common in dioritic and granitic rocks further to the north at Sorel Point. Figure for scale. BGS © UKRI 2020.

Photo 13: Group D granite in an exposure located close to where Photo 1 was taken. The rock has abundant tabular crystals of orange alkali feldspar, which in this exposure may show a weak vertical alignment. Pen for scale. BGS © UKRI 2020.

Photo 14: Group D granite, with typical coarse orange crystals of alkali feldspar, enclosing partly rounded fragments of grey diorite or gabbro, which were probably sourced locally from Group A country rocks. Pen for scale. BGS © UKRI 2020.

Photo 15: The contact between Group D granite (left) and pink aplogranite (Group A) at one edge of the 'band of brown rocks' described in Photo 1, which crops out in aplogranite near the northernmost tip of Sorel Point. The yellowish rock formed along the contact may be a chilled margin in the Group D granite. Pen for scale. BGS © UKRI 2020.

Map of the site boundary on a topographic base

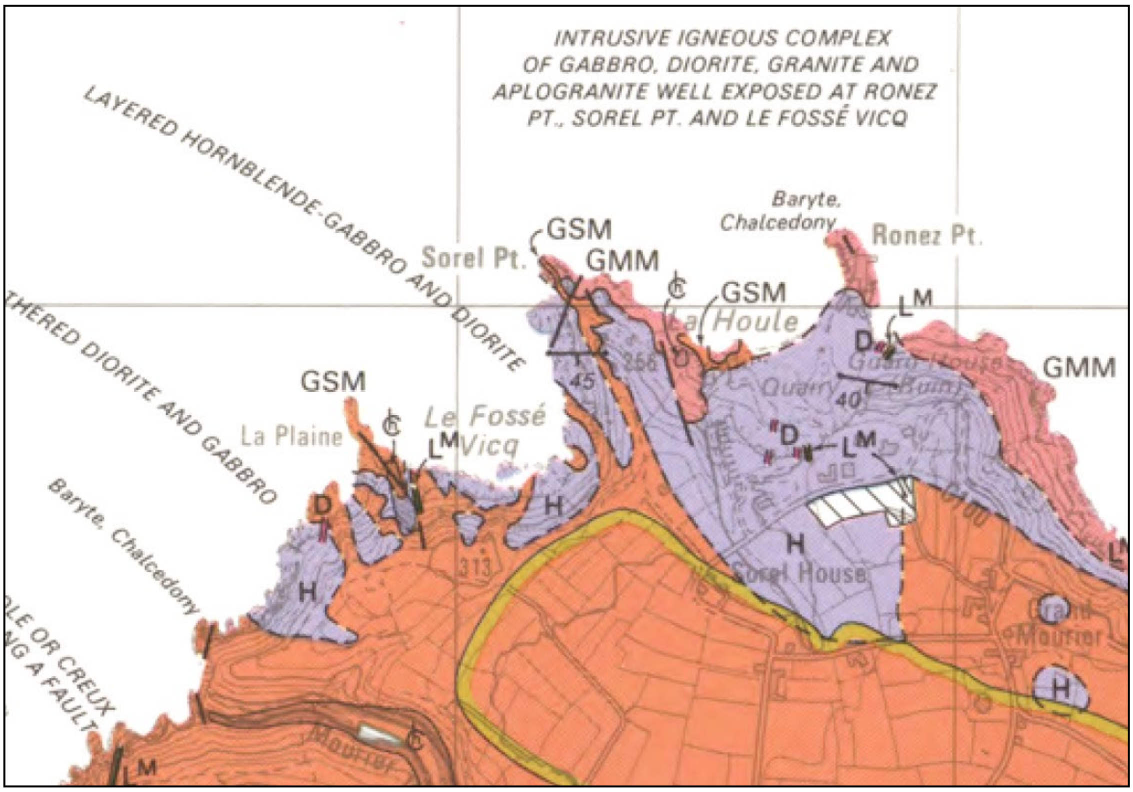


Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph

Imagery ©2020 Government of Jersey.

Published geological map of the site



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.11 SITE NAME: LA MOTTE, LE NEZ AND LE CROC, SSI

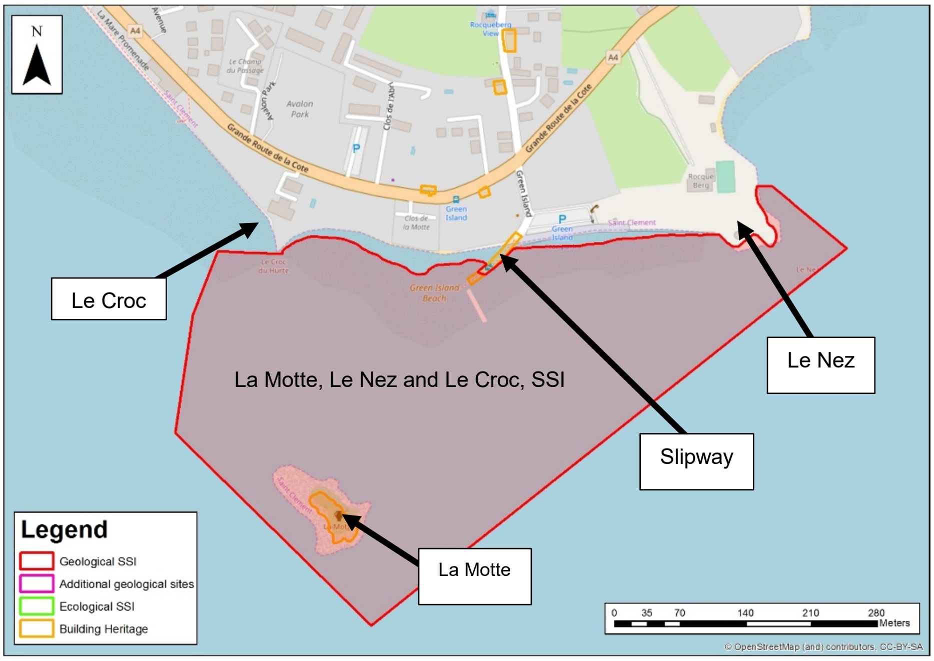
Site Information:

The La Motte, Le Nez and Le Croc site, near the south-east extremity of Jersey, comprises a small tidal island (La Motte, or Green Island) and intertidal exposures extending discontinuously from La Motte to the nearby rocky promontories of Le Croc and Le Nez. The bedrock is a lithologically variable part of the *South-east igneous complex*. Each of three main outcrops in the site displays a distinct range of igneous features that collectively present a window into a dynamically evolving magma chamber. The site includes good examples of the *Jersey Main Dyke Swarm*, and both La Motte and Le Nez provide excellent viewpoints over the largest intertidal rock platform on the Jersey coast.

The top surface of the island, which is several metres above MHWS, is underlain by 0.25 m of raised beach gravel that is succeeded by up to 4 m of loess and capped by *c.* 0.3 m of blown sand and soil. The island has significant archaeological importance, including cist graves. These were thought to be Neolithic, but it is now thought that these graves date to the 10th and 11th centuries AD.

National Grid Reference: Mid-point: 44383, 62998 West end: 44049, 62941 East end: 44764, 63128	**Site Type:** Natural exposure
Site Ownership: Part public and part Société Jersiaise	**Current Use:** Open country, coastal
Field Surveyors: M Gillespie, R Kendall, J Everest and L Hughes	**Current Geological Designations:** Geological SSI
Date Visited: 13 October 2019	**Other Known Designations:** The site encompasses two Building Heritage sites (La Motte and Green Island Slipway).

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** *South-east igneous complex* (unnamed unit)
Rock Types: Diorite, gabbro, lamprophyre and granite	
Age: Ediacaran Period (late Precambrian)	**Formation:** Jersey Main Dyke Swarm
Rock Types: Basalt/dolerite	
Age: Holocene	**Formation:** Blown sand
Rock Types: Fine to medium buff sand	
Age: Pleistocene	**Formation:** Loess
Rock Types: Fine silt and quartz grains with evidence of freeze thaw	
Age: Pleistocene	**Formation:** Loess
Rock Types: Silt	
Age: Pleistocene	**Formation:** Beach
Rock Types: Coarse gravel and pebbles	

Site Description:

Introduction

The Green Island site lies within the outcrop of the largest mass of 'diorite and gabbro' in the *South-east igneous complex*, and these igneous rocks are the main feature of interest at the site. There are three main outcrops, each of which presents a range of igneous features indicative of different magma environments. The site is one of the best places in Jersey to see large outcrops of relatively basic (silica-poor) igneous rocks and to compare the textures that result from different magma processes.

Igneous layering – probably formed within a single batch of magma that was undisturbed as it cooled and crystallised – can be examined in a large outcrop at Le Nez. By contrast, exposures around Le Croc consist of multiple m-scale intrusions of basaltic, dioritic and granitic rocks, which were emplaced more or less contemporaneously but tend to cross-cut each other. Finally, spectacular examples of rocks produced by the intimate interaction (fragmentation and partial assimilation) of compositionally distinct magmas are exposed around La Motte. Collectively, the outcrops present a revealing window into the range of processes that can operate in dynamically evolving magma chambers.

The bedrock on the island is overlain by beach deposits, loess and windblown sand of variable thickness. In comparison to the rest of Jersey, the loess deposits are relatively well exposed on La Motte and are clearly visible in multiple sections around the island (Photo 17). The unconsolidated Quaternary deposits on the island also contain significant archaeological evidence of human occupation during the 4th and 11th centuries AD. These include a number of excavated cist burials. Consequently, the upper part of these deposits and the associated palaeo-land surface are protected under Building Heritage status. A number of measures have been employed to try to minimise the effects of erosion by wave action, including a protective wall and netting over the sediments on the more exposed south-western side of the island.

Bedrock Units

South-east igneous complex

The *South-east igneous complex* is one of three major intrusion complexes in Jersey. Several lithologically distinct components have been mapped within it (Figure 1), including large (km-scale) masses of basic rock ('diorite and gabbro') and three main variants of granite (IGS, 1982).

Dark grey diorite, grading locally to gabbro, is the earliest component of the *South-east igneous complex*; it forms several discrete, km-scale outcrops. The largest outcrop underlies the intertidal reef off La Grève d'Azette and extends inland as far as Grouville; another substantial (km-scale) mass forms a cluster of reefs to the south of Seymour Tower at the south-east extremity of the extensive reef lying south of La Rocque. Primary igneous layering in diorite and gabbro is preserved in several intertidal exposures, including those near La Grève d'Azette, at Le Nez and in the skerries south of Seymour Tower. The consistent character and orientation of the layering, which generally dips towards the north-east at around 60–70^0 (*c.* 30^0 near Seymour Tower), suggests that these widely separated outcrops were once part of the same large body of layered rocks, which was perhaps the earliest expression of the *South-east igneous complex*. Evidence for a dynamic magma environment, in the form of intimately associated, broadly contemporaneous but compositionally distinct basic, intermediate and siliceous rocks, is well displayed in several localities. Notable examples include the exposures between Le Croc and La Motte, at Havre des Pas Lido and at Elizabeth Castle (where the siliceous component is part of a km-scale mass sometimes referred to as the *Fort Regent Granophyre* [e.g., Bishop *et al*., 2003]). Injections of basic and siliceous magma may have destroyed early layering in parts of the magma chamber, and the early body of layered rocks may have been tilted and dismembered when large masses of granite magma (forming the three main granite variants of the *South-east igneous complex*) were subsequently emplaced.

The strongly porphyritic *Dicq granite* is the least extensive of the three mapped variants of granite in the *South-east igneous complex*, its outcrop being restricted mainly to a portion of the intertidal zone south of Grande d'Azette and near Havre des Pas where the magma has cut and locally mingled with early dioritic rock. A further small (*c.* 100 x 100 m) outcrop of *Dicq granite* is mapped *c.* 1.2 km north-east of Le Dicq. The essentially non-porphyritic *Longueville granite* underlies a significantly larger area of ground beneath the south-east part of St Helier and to the north of the largest body of dioritic rock; however, exposure is very poor over most of the outcrop. *Longueville granite* and *Dicq granite* are probably broadly contemporaneous (see the description for the *Le Dicq to Havre des Pas* site). *La Rocque granite* (called 'Le Hocq granite' by Lees [1986] and 'Le Hocq–La Rocque–Gorey granite' in Bishop *et al*. [2003]) is by far the most extensive granite component of the *South-east igneous complex*, at least onshore. It forms much of the intertidal reef in St Clement's Bay and the mainland north of there as far as Mont Orgueil. Cross-cutting relationships with dykes in the *Jersey Main Dyke Swarm*, well displayed in intertidal exposures near La Grève d'Azette, indicate that *La Rocque granite* is also the youngest of the main granite components in the *South-east igneous complex* (IGS, 1982).

Unlike the other two large intrusion complexes in Jersey, the main components of the *South-east igneous complex* are not arranged in a pattern of concentric zones, but instead form irregularly distributed and irregularly shaped, discrete, km-scale masses dominated by either diorite and gabbro or granite (IGS, 1982). The onshore outcrop of the *South-east igneous complex* (including the intertidal reefs) is at least 10 x 7 km in extent. However, granitic and dioritic rocks crop out on the seafloor for a considerable distance to the south, west and east of the south-east Jersey coast (BGS, 2000), suggesting that the onshore outcrop of the *South-east igneous complex* is just a small part of a much larger intrusive complex (Figure 2). Indeed, the offshore outcrop of intrusive igneous rocks extends unbroken along the entire south coast of Jersey, suggesting that the *South-west igneous complex* and *South-east igneous complex* are part of the same large outcrop of intrusive igneous rocks (Figure 2).

Unlike the other two main intrusion complexes in Jersey, a U-Pb zircon age has not been reported for the *South-east igneous complex*. Instead, a range of ages between *c.* 583 and 527 Ma has been reported; they are based on the K-Ar isotope system (Adams, 1967; D'Lemos *et al*., 1992). The K-Ar system is prone to resetting during rock alteration events, so it generally does not produce accurate dates for the crystallisation of coarse-grained igneous rocks; consequently, results should not be compared directly with U-Pb zircon ages. Similarities in the characteristics of cross-cutting dykes (*Jersey Main Dyke Swarm*), and the fact that intrusive plutonic rocks form an unbroken outcrop offshore between the south-west and south-east extremities of Jersey (Figure 2), suggest that the *South-west igneous complex* and *South-east igneous complex* are broadly contemporaneous. On this basis, the *South-east igneous complex* was probably emplaced during the Ediacaran Period, as a feature of the Cadomian Orogeny.

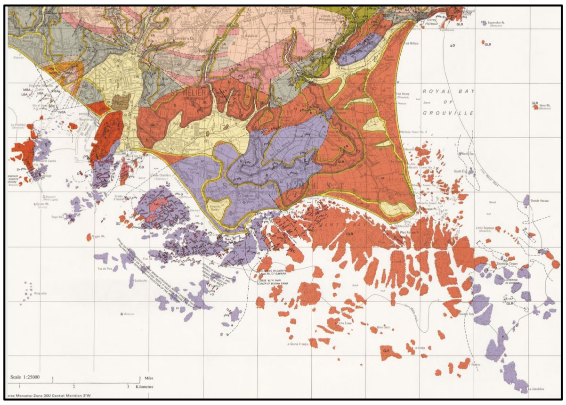


Figure 1. Geological map of the *South-east igneous complex*. From IGS (1982).

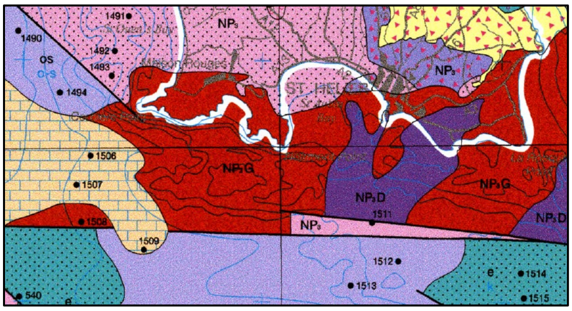


Figure 2. Map of onshore and offshore bedrock geology around the southern half of Jersey (coastline in white) showing the apparent offshore continuation of the *South-west igneous complex* and *South-east igneous complex*. From BGS (2000).

Jersey Main Dyke Swarm

The *Jersey Main Dyke Swarm* is the name assigned by Lees (1986) to the obvious concentration of dykes that crop out within the E–W-trending area of ground underlain by the two main igneous complexes in south Jersey. The dykes typically are steeply dipping, and most are less than 1 m wide; good coastal exposures reveal that they account for around 10% of the outcrop locally. The swarm is particularly well exposed, and particularly abundant, in the extensive intertidal reef to the west and east of Le Croc in south-east Jersey.

The dykes display strong preferred orientations: E–W in the *South-west igneous complex* and NE–SW in the *South-east igneous complex*. A small proportion of dykes have a broadly N–S trend; these must have opened in a stress regime different from the stress regime of those forming the main part of the swarm, indicating that the swarm as a whole had a multistage emplacement history.

Dykes of basic (i.e., basalt and dolerite) composition predominate, but Lees (1986) noted that those cutting the *South-west igneous complex* are mainly dolerite, whereas those cutting the *South-east igneous complex* display a broader range of compositions, including dolerite, microdiorite, lamprophyre and rhyolite (or microgranite). Where they occur together, for example, in exposures on the foreshore at Mont Orgueil, the basic (doleritic) dykes often cut the siliceous dykes. Many dykes are porphyritic; small phenocrysts of plagioclase and ferromagnesian minerals predominate in dykes of basic composition, while phenocrysts of quartz and feldspar occur in siliceous examples. Some dykes are composite, containing both basic and siliceous components; in such cases, basic margins and siliceous centres are common.

The dykes were emplaced during and shortly after the later stages of the assembly of the two main igneous complexes in south Jersey (Lees, 1986); this places them in the Ediacaran Period, as a late-stage feature of the Cadomian Orogeny. Based on whole-rock chemical analyses, Lees (1986) described the swarm as having a calc-alkaline character of a potassium-rich ('high-K') type, 'characteristic of basalts generated at an active continental margin'.

Dykes of similar lithologies, and often with similar trends, occur in other parts of Jersey, although they are relatively rare; many are probably genetically related to the *Jersey Main Dyke Swarm*.

Bedrock Features

Le Nez

The large outcrop (roughly 70 x 30 x 4 m high at low tide) at Le Nez is one of the best places in Jersey to see primary layering in igneous rocks. This phenomenon occurs when bodies of silica-poor magma are allowed to cool and crystallise without being physically disturbed, for example, by new batches of magma coming into the chamber. Unlike silica-rich magma, silica-poor magma has low viscosity, and this allows crystals of different minerals to 'settle' or 'float' in the magma according to differences in their density and shape; in this way, they become concentrated into horizontal layers (or bands). Adjacent bands in a layered sequence consist of different minerals, or the same minerals in different proportions, and for this reason they are usually distinct in terms of colour and texture. Rocks produced in this way are sometimes referred to as cumulate rocks. Some of the most important ore bodies in the world are cumulate rocks in which metal-rich minerals have become concentrated in layers.

Primary layering is rare in igneous rocks, partly because many magmas are too viscous (thus preventing different minerals from becoming selectively concentrated) and partly because when layering does form in magma chambers, it is often destroyed when new magma is injected into the chamber.

The outcrop at Le Nez consists of coarse-grained diorite and gabbro in which layering is visible in places as faint bands, with the bands dipping at around 60^0 towards the north-east (Photos 1–3). The dip indicates that the layered rocks were tilted at some point after they crystallised. The bands are defined by variations in the crystal size and in the relative proportions of dark minerals (mainly hornblende) and light minerals (mainly plagioclase feldspar).

The detailed investigation of the site (e.g., Wells and Bishop, 1955; Bishop and Key, 1983, 1984) has revealed compositional layering on at least two scales. Within the outcrop as a whole, layered diorites pass up into layered gabbros, which in turn pass up into pegmatitic diorite. On a smaller scale, the diorite at the base of the sequence consists of layers around 1 m thick in which dark (hornblende-rich) rock at the base passes up into lighter (less hornblende-rich) diorite and then into quartz-diorite at the top (Photo 4); the quartz-diorite sometimes contains elongate and aligned crystals of hornblende. The layered gabbros can have a distinctive 'spotted' character, produced by large, poikilitic (sieve-like) crystals of hornblende up to 3 cm across, and in places they display thin (cm-scale) layers of relatively light and dark rock, often accompanied by very coarse, pegmatitic rock. Some hornblende crystals in the gabbro have cores of relict pyroxene. Towards the top of the layered gabbros, pegmatitic diorite forms patches that are parallel to or cut across the layers (Photo 5).

Layered rocks similar to those at Le Nez can be traced over a distance of nearly 2 km along this part of the Jersey coast, from the reefs at Grève d'Azette in the west to Havre des Fontaines in the east (where the dioritic rocks are in contact with younger granite). The orientation of the layering remains more or less consistent throughout, suggesting that there must be a considerable thickness of layered rocks (e.g., Bishop *et al*., 2003).

Unlayered parts of the outcrop at Le Nez consist of relatively homogeneous, coarse-grained diorite (and possibly gabbro) cut locally by veins of pegmatitic rock formed of coarse pink feldspar and white quartz. In places, the coarse-grained (plutonic) rocks are cut by sheets and irregular patches of fine-grained, dark grey basaltic rock. Irregular shapes and a lack of chilled margins suggest that these were emplaced broadly contemporaneously with the magma that produced the layered rocks (i.e., they are synplutonic). Later, NE-trending dykes of basalt or dolerite cut the outcrop locally and are probably part of the *Jersey Main Dyke Swarm*.

Le Croc

Low outcrops on the beach at Le Croc, which cover an area of around 60 x 50 m at low tide, are formed of numerous sheets and irregular masses of lithologically variable igneous rocks. The oldest component, a mass of very dark, coarse-grained, hornblende-rich rock, crops out a few metres south of the southernmost point of the sea wall at Le Croc (Photo 6). Viewed in thin section, the rock has phenocrysts of brown amphibole and more plagioclase than alkali feldspar; on this basis, it has been classified as a type of lamprophyre known as camptonite (Bishop and Bisson, 1989). The lamprophyre is cut by several later generations of magmatic rocks, including grey dioritic rocks that are mingled and mixed locally, brick-red microgranite with phenocrysts of quartz and feldspar, and dark grey basalt that is weakly porphyritic in places (Photos 7 and 8). Where these intrusions are in contact with each other, the boundaries are planar to convoluted and sharp to diffuse, and they show no sign of chilling, indicating that these intrusions were broadly contemporaneous. They are all part of the *South-east igneous complex*.

A suite of basaltic dykes, generally <1 m wide and trending broadly NE–SW, cut all of the components described above and are probably part of the *Jersey Main Dyke Swarm* (Photo 7). The margins of some dykes are green because weak deformation and hydrothermal alteration focused along the margins have allowed the mineral epidote to replace primary minerals in the dyke.

La Motte

The extensive bedrock outcrop surrounding La Motte is roughly 100 x 100 x 5 m in height at low tide. The outcrop, and the boulders and cobbles that sit on it, presents a spectacular example of magmatic breccia, formed when solid rock was fragmented as magma was emplaced forcefully into the same space, enclosing the resulting rock fragments (Photos 7–10). In this case, the older rock is dark grey diorite and the younger rock is orange granitic rock (granodiorite and quartz-diorite according to Bishop *et al*., 2003); the contrasting colours of these two components reveal a spectacular range of textures. Patches of pegmatitic rock are developed locally in the host diorite (Photo 12).

When magma encloses rock fragments, the fragments can start to break down and become absorbed by the magma in a process known as assimilation. Assimilation is one of the main processes by which magmas can change their composition. The evidence for assimilation varies considerably within the outcrop at La Motte. Diorite fragments with sharply defined, angular boundaries (Photo 9) are evidence that essentially no assimilation happened (at the outcrop scale) in some places. However, in some exposures, the diorite fragments have rounded and rather diffuse boundaries (Photo 10), and in places the boundaries are so diffuse that they have become ‘shadowy’ and hard to see (Photo 11); the latter examples are evidence of reasonably advanced assimilation at the outcrop scale. Sheets of brick-red microgranite, possibly of the same generation as that seen at Le Croc, cut the magmatic breccia in places (Photo 8).

Quaternary Sediments

The steep, incised sea cliffs that surround La Motte result in exposures of Quaternary sediment overlying bedrock on all sides of the island. Exposed at virtually all the locations around the island is a coarse gravel-to-boulder layer composed of subangular clasts of locally derived diorite. These coarse-grained sediments have been interpreted as beach deposits and tentatively assigned an Ipswichian age by Keen (1993). This conclusion is possibly supported by the more recent work of Renouf and James (2011), who argue that all beach deposits relating to the 8 m shoreline are likely to be Ipswichian (*c.* 120 ka BP) in age. In one exposed section on the south-eastern side of La Motte, a weathered fault zone within the bedrock has been eroded out to form a wedge-shaped slot (50 cm wide at the top, narrowing to 5 cm at its base), which was later infilled by sub-rounded pebbles and coarse gravel (Photo 16). This gravel grades upwards into the overlying Quaternary beach deposits.

Overlying the beach material is a 3–4-m-thick sequence of sandy loess deposits (Photo 18). The lowest unit, within the loess, is *c.* 0.5-m-thick and contains common quartz sand grains; it was interpreted by Keen (1978, 1982) as having been deposited in an open, treeless, aeolian environment. This lower unit is overlain by sand containing a distinctive, disrupted laminated structure (Photo 18), which is thought to be indicative of intense freeze thaw, with similar structures having been described in Kesselt in Belgium. It has been suggested by Keen (1993) that the Quaternary sequence at La Motte records a transition from the relatively warmer Early Devensian into the colder Middle Devensian, with the Kesselt-style loess deposits indicating deposition under the intensely cold Late Devensian period. The remainder of the Quaternary sequence comprises *c.* 0.3 m of shelly blown sand, which is thought to most likely be Holocene in age; it is correlated with other windblown sand deposits in Jersey, for example, at Grouville Bay and St Ouen's Bay.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Public road to parking area (Green Island beach parking)
Access	A gently inclined slipway provides access to the beach (and the site) from the parking area.
Safety of access	A slipway leading from the parking area provides safe access to the beach; from there, the three main outcrops (at Le Nez, Le Croc and La Motte) can be reached by an easy walk. The site lies entirely within the intertidal zone, which is a mixture of sandy beach and rough, rocky ground that is exposed to wind and waves. The state of the incoming tide is difficult to gauge from the south side of La Motte, and it is easy to become cut off there.
Safety of exposure(s)	All of the main exposures are in the intertidal zone, which is a discontinuous, rough, rocky platform exposed to wind and waves. There is no path on the platform, and the ground here may be slippery and presents many trip hazards; mild scrambling is required to access some parts. The intertidal zone in places is crossed by shallow channels at low tide and is subject to rapid tidal movements.
Current condition	Bedrock exposures are generally clean and sound. Barnacles, limpets and algae coat the rock to varying degrees, but there is little seaweed. The flanks of La Motte and the grassy platform forming its top surface are worn in places by footfall.
Current conflicting activities	None
Restricting conditions	All exposures are in the intertidal zone and will be inaccessible at times.
Nature of exposure(s)	Bedrock exposures comprise large expanses of rough rock, with up to 4 m of vertical relief at La Motte and Le Nez. Green Island is a small, flat-topped grassy knoll sitting above MHWS.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Prehistoric features are described in the La Motte geodiversity site report. La Motte is a unique site in Jersey, as it has several components that include ritual and domestic elements. There is also important environmental evidence relating to changes in sea level (HER Number 0200089; Listed place CL0089). Finds: core (HER Number 0200212), basalt (HER Number 0200213), clay pipe (HER Number 0200183). Samares Methodist Church, an early-20th-century chapel of historical interest, contributes to the streetscape (HER Number 0200017; Listed building CL0017). Tilsden, an early-19th-century 'fisherman's' cottage with some original features surviving, contributes to the streetscape's character (HER Number 0200068; Listed building CL0068).
Aesthetic landscape	The site includes a pleasant beach, but it is low-lying and adjacent to an urban area. The parking area and the summit of La Motte provide extensive and impressive views over a large intertidal rock platform (or reef).
History of Earth science	None
Economic geology	None

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Regional	Excellent	Referenced	X
Structural geology				
Palaeontology				
Geomorphology	Local	Good	References	

Geoscientific Value of the Site
The site is one of the best places in Jersey to see large outcrops of relatively basic igneous rocks and to compare the textures that result from different magma processes. Collectively, the outcrops present a revealing window into many processes that can operate in dynamically evolving magma chambers.

Assessment of Site: Current Site Usage	
Community	The modern beach is used for typical beach-related recreational activities.
Education	Used by local geology groups
Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust, but the superficial deposits forming La Motte are vulnerable to erosion. Existing measures include a sea wall and meshing, which has been prone to coming loose due to storms and prevailing winds.
Potential use	The La Motte, Le Nez and Le Croc site is of potential use, as it exposes rocks of the *South-east igneous complex*. Each of three main outcrops in the site displays a distinct range of igneous features that collectively present a window into a dynamically evolving magma chamber. The site includes good examples of the *Jersey Main Dyke Swarm*, and both La Motte and Le Nez provide excellent viewpoints over the largest intertidal rock platform on the Jersey coast. The top surface of the island, with its Quaternary deposits and significant archaeological importance, provides an opportunity to talk about these features. The erosion evident here may also provide an opportunity to communicate the importance of the conservation of vulnerable deposits, such as those on the island. This site is of use for researchers, education and tourists. The site has ample space for interpretation boards and could benefit from leaflets or be part of geotrails, especially because of the ease of access and local facilities. There is also the opportunity here to involve local guides who lead parties of tourists at low tide; they could include the geology in their tours of the reefs at low tide.

Site Photos:

Photo 1: Typical character of layered rock in the large outcrop at Le Nez. The layering in this exposure, which is around 3 m high, is quite subtle, but two principal layers around 1 m thick are visible. The boundary between the layers runs approximately through the centre of the exposed surface, trending from the top right to the bottom left and separating generally darker diorite (above) from lighter diorite (below). The exposure is cut by a thin sheet of pink felsite, which is broadly parallel to the layering. BGS © UKRI 2020.

Photo 2: Typical character of layered diorite and gabbro in the large outcrop at Le Nez. Multiple parallel bands of darker and lighter rock trend from the top left to the bottom right of the exposure. Pen for scale. BGS © UKRI 2020.

Photo 3: Typical character of layered diorite and gabbro in the large outcrop at Le Nez. Multiple parallel bands trend from the top right to the bottom left of the exposure. Pen for scale. BGS © UKRI 2020.

Photo 4: Quartz-diorite formed of large, often elongate crystals of black hornblende with interstitial white plagioclase and grey quartz in the large outcrop of layered rocks at Le Nez. In the top part of the image, a convoluted boundary separates the coarse quartz-diorite from finer-grained rock of apparently similar composition. Pen for scale. BGS © UKRI 2020.

Photo 5: Elongated patches of pegmatitic diorite in finer-grained rock in the large outcrop at Le Nez. The patches of pegmatitic rock are aligned parallel to the general trend of layering in the outcrop. Pen for scale. BGS © UKRI 2020.

Photo 6: Looking south-east over the outcrop at Le Croc at low tide. La Motte (Green Island) forms the small area of elevated ground on the horizon. Dark rocks below the figure and in the foreground are hornblende-rich lamprophyre. This rock, the oldest in the outcrop, is cut by irregular patches and sheets of grey basaltic and dioritic rocks, and pink to red granitic rocks, which comprise the bulk of the outcrop at Le Croc. BGS © UKRI 2020.

Photo 7: Close-up of exposed rocks beneath the standing figure in Photo 6. Dark grey, hornblende-rich lamprophyre is cut by sheets of pink granitic rock, and both are cut by a thin basalt dyke that cuts vertically through the outcrop beneath the pen. The meladiorite and granitic rock are part of the *South-east igneous complex*, while the basalt dyke is probably a component of the Jersey Main Dyke Swarm. Pen for scale. BGS © UKRI 2020.

Photo 8: Cross-cutting relationships among multiple lithologically distinct components of the *South-east igneous complex* in the outcrop at Le Croc. A sheet of blue-grey basaltic rock in the foreground cuts a body of pale pink (probably granitic) rock and a body of grey (possibly dioritic) rock (beneath the pen). In the background, there is an outcrop of brick-red microgranite. Pen for scale. BGS © UKRI 2020.

Photo 9: Large fragments of grey diorite enclosed in pink granite in a large exposure on the west side of La Motte. BGS © UKRI 2020.

Photo 10: Cross-cutting relationships among multiple lithologically distinct components in a boulder on the west side of La Motte. Two subhorizontal sheets of brick-red microgranite cut earlier rock in which fragments of grey diorite are enclosed in pale orange granitic rock. Pen for scale. BGS © UKRI 2020.

Photo 11: Fragments of meladiorite with sharp, angular boundaries enclosed in pale orange granite in an exposure on the north side of La Motte. Parts of the outcrop are covered in beach sand that looks very similar to the granite. Pen for scale. BGS © UKRI 2020.

Photo 12: Fragments of meladiorite, with boundaries ranging from sharp and angular to diffuse and rounded, enclosed in pale orange granite in an exposure on the north side of La Motte. Pen for scale. BGS © UKRI 2020.

Photo 13: Diffuse, shadowy fragments of meladiorite enclosed in pink granite in an exposure on the west side of La Motte. Pen for scale. BGS © UKRI 2020.

Photo 14: Pegmatitic diorite in a boulder on the west side of La Motte. The rock consists of large, stubby crystals of black hornblende, pale yellow plagioclase feldspar and long frond-like crystals of a pale green mineral – possibly actinolite amphibole that has replaced an earlier mineral. Pen for scale. BGS © UKRI 2020.

Photo 15: La Motte from Green Island car park, visible above the horizon on the right-hand side of the image. The reef complex is clearly visible at low tide in this image. Loessic and gravelly deposits occur at Icho Tower (a Martello tower), seen here on the horizon towards the left side of this image. BGS © UKRI 2020.

Photo 16: Panoramic view from the top of the island of La Motte, looking south-east across the extensive diorite reef. BGS © UKRI 2020.

Photo 17: Exposed, infilled, weathered fault in diorite bedrock of the island of La Motte. Note the smooth upper surface of the bedrock. The fault is infilled by a clast-rich marine beach deposit of sub-rounded cobble to pebble-grade clasts with an orange-buff, fine, sandy silt matrix. This beach sediment is interpreted as having likely been deposited during the Ipswichian; it is correlated with 8 m raised shoreline deposits around Jersey and in the wider English Channel region. BGS © UKRI 2020.

Photo 18: Partially vegetated *c.* 4-m-high section on the northern side of the island of La Motte showing a loess sequence. It is assumed by the authors that the visible cobbles exposed towards the top of the section are related to the archaeology of the island; as a result, such a unit has not been described in the palaeoenvironmental literature. BGS © UKRI 2020.

Photo 19: Close-up of an upper loess sequence with lamellar structures related to intense freeze-thaw conditions, probably dating from the Middle to Late Devensian transition *c.* 30 ka BP. BGS © UKRI 2020.

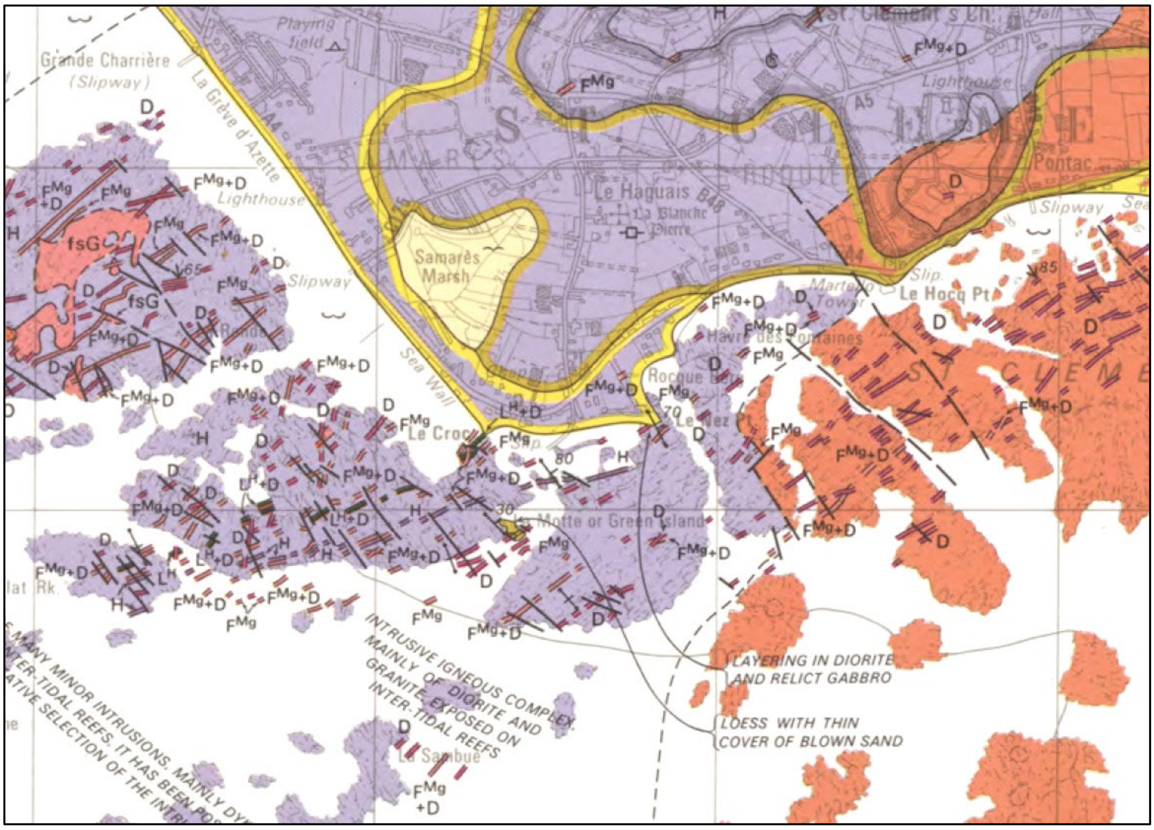
Map of the site boundary on a topographic base

Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph

Imagery ©2020 Government of Jersey.

Published geological map of the site

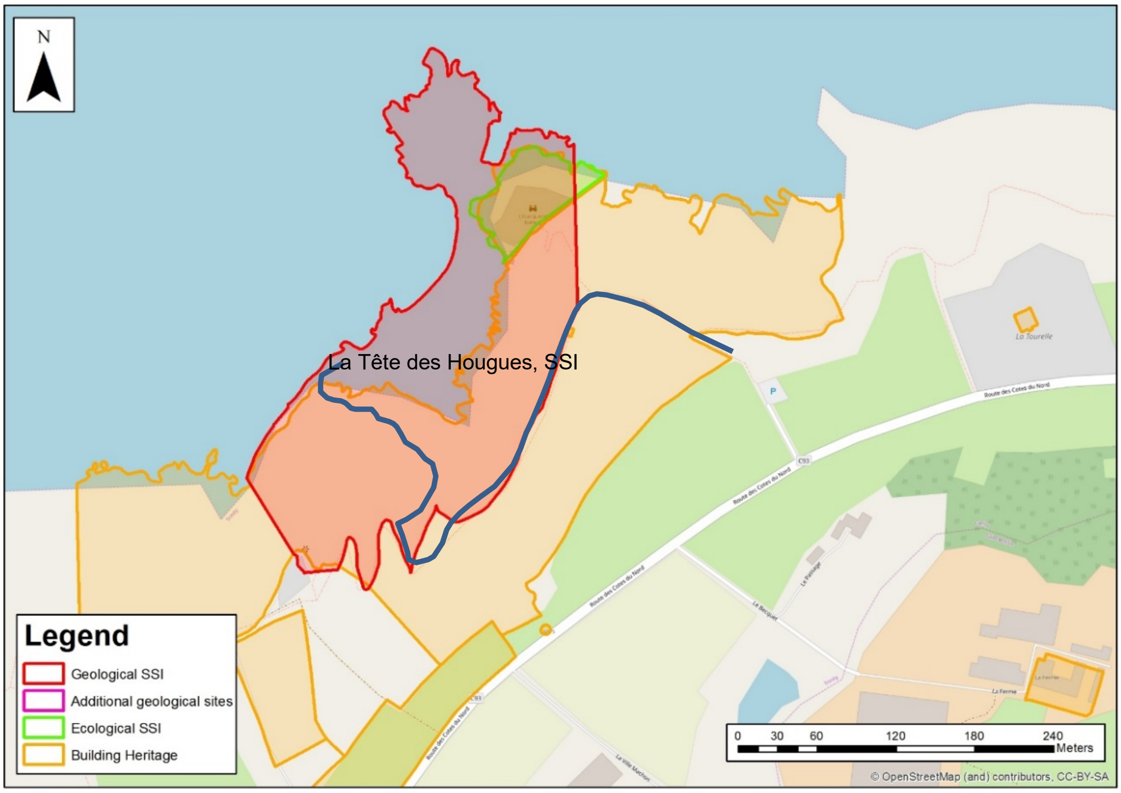


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.12 SITE NAME: LA TÊTE DES HOUGUES, SSI

Site Information:	
This site is within a small bay to the east of L'Étacquerel Fort at La Tête des Hougues, in the south-east corner of Bouley Bay in north-east Jersey. In this bay, the *Rozel Conglomerate Formation* unconformably overlies the Bouley Rhyolite Formation. The rhyolites comprise flow-banded lavas and ignimbrites, which often have spherulitic textures. The top of the formation has an irregular, sometimes deeply eroded surface that includes a fossil scree deposit. The overlying *Rozel Conglomerate Formation* comprises mainly coarse conglomerates with some sandstones and mudstones deposited in alluvial fans with a source area to the north of Jersey.	
National Grid Reference: Mid-point: 44900, 71374 West end: 44740, 71281 East end: 44993, 71417	**Site Type:** Natural section
Site Ownership: Part private, part public and part National Trust for Jersey	**Current Use:** Open country
Field Surveyors: RS Kendall and S Arkley	**Current Geological Designations:** Geological SSI
Date Visited: 22 and 27 September 2019	**Other Known Designations:** L'Étacquerel Fort, Ecological SSI, and L'Étacquerel Flint Scatter Area, Folio number TR0215 (Building Heritage).

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA. Path to outcrop is shown by blue line.

Stratigraphy and Rock Types:	
Age: Latest Precambrian (Ediacaran)	**Formation:** Bouley Rhyolite Formation
Rock Types: Ignimbrites and rhyolites	
Age: Upper Cambrian to Ordovician	**Formation:** *Rozel Conglomerate Formation*
Rock Types: Coarse conglomerates with subordinate sandstones and mudstones	

Site Description:

Introduction

This site comprises outcrops within a small cove close to the headland at La Tête des Hougues in the central part of Bouley Bay in north-east Jersey. In this bay, flow-banded lavas and ignimbrites of the Bouley Rhyolite Formation have an irregular, sometimes deeply eroded top surface, which includes fossil screes that would have spalled from areas of high ground in the Precambrian. Unconformably overlying this surface are coarse conglomerates, sandstones and mudstones of the *Rozel Conglomerate Formation*, which was deposited in alluvial fans from sources to the north of Jersey (Went, 1991).

Bedrock Units

Bouley Rhyolite Formation

The oldest rocks exposed at La Tête des Hougues are ignimbrites of the Bouley Rhyolite Formation (specifically the Upper and Middle Bouley Ignimbrite of the Bouley Rhyolite Formation). The top surface of the ignimbrites is very irregular; in places, there is a variation of 2 to 3 m in elevation across the bay. Above this surface is an irregular layer of rhyolitic rubble interpreted as scree deposits shed from topographic highs in an exhumed topography (Went, 1991). This surface was exposed to erosion during or after the Cadomian Orogeny, possibly during the early Palaeozoic and before the deposition of the overlying *Rozel Conglomerate Formation*.

The Anne Port Rhyolite, a unit within the Bouley Rhyolite Formation, has been dated by Miller *et al.* (2001), using U/Pb isotopes, to *c.* 583 Ma (Latest Precambrian).

Rozel Conglomerate Formation

At La Tête des Hougues, the base of the *Rozel Conglomerate Formation* can be seen where it unconformably rests on the deeply eroded top surface of the Middle and Lower Bouley Ignimbrites (units within the Bouley Rhyolite Formation). The *Rozel Conglomerate Formation* is a succession of alluvial fan deposits, and at this locality, at the base of the formation, there are 4 m of upwards-coarsening silty mudstones and fine pebble conglomerates, followed by a 3-m-deep channel. Overlying this erosional surface is 28 m of upwards-fining coarse debris flows and stream flood conglomerates. Two main units are identified at La Tête des Hougues: a lower prograding fan of reworked material and an upper unit that is thought to indicate avulsion and the gradual abandonment of a fan lobe. The *Rozel Conglomerate Formation* was deposited on the northern flank of a minor WNW-trending extensional basin, one of several identified in the Channel Islands, northern Brittany and Normandy, with its source area thought to be a hinterland to the north of the present-day outcrops (Went, 2005; Went *et al*., 1988).

The *Rozel Conglomerate Formation* is the youngest of the sedimentary hard rock formations in Jersey (Bishop *et al*., 1989). Its actual age is uncertain but it is thought to have been deposited in the late Cambrian to Early Ordovician. Went and Andrews (1990) suggest that the *Rozel Conglomerate Formation* was likely deposited in the later stages of the Cadomian Orogeny. Miller *et al*. (2001), however, link the deposition of the *Rozel Conglomerate*

Formation to deposition in minor extensional basins associated with plutonism, which they date to *c.* 480 Ma (mid-Ordovician). Adams (1976) gave a date of 427 ± 13 Ma (recalculated as 435 ± 13 Ma) for a dyke that intrudes conglomerates at La Coupe Point; this date could provide a minimum age.

Weathered profiles through igneous basement rocks, such as the scree deposits and deeply eroded surface of the Anne Port Rhyolite Formation seen at La Tête des Hougues, also occur beneath Lower Palaeozoic terrestrial sequences in Alderney (Alderney Sandstone Formation) and northern Brittany (Erquy-Fréhel Group). These are thought to have developed during the early Palaeozoic and are possibly related to a phase of rifting and subsequent molasses deposition, perhaps in response to the uplift and subaerial exposure of the Cadomian belt during the Cambrian (Went, 1991).

Structures

The *Rozel Conglomerate Formation* is folded into a WNW-trending syncline. The syncline has a sinuous axial trace that runs just south of the coastline between Tour de Rozel and Fliquet Bay and is caused by the open NE-trending folds that are superimposed on the main axis. At La Tête des Hougues, the purple laminated mudrocks at the base of the sequence have a slaty cleavage that strikes 138° and dips moderately steeply towards the north-east. Elsewhere, there is a SE-trending, sub-vertical fabric that flattens and rotates pebbles. This fabric is particularly well developed at St Catherine's breakwater, where it strikes 120° (Helm, 1984).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	There is a small car park at GR 45139, 71345, and access via a dirt track just to the east of La Ville Machon. To access the beach, walk north from the car park, walking towards L'Étacquerel. There is a coastal path that heads south-west and another path heading north to the headland at the south end of the bay.
Safety of access	The site is not accessible with a car, as reaching it involved scrambling down from a very overgrown path and then across rocks, which are potentially slippery just after high tide or after rain. There is also the possibility of being cut off by the tide.
Safety of exposure(s)	There is a danger of falling debris from high cliffs in parts of the section and the rocks are slippery when wet.
Access	Open access but please see notes above about safety
Current condition	Good
Current conflicting activities	Site boundary overlaps with L'Étacquerel Fort, Ecological SSI, and L'Étacquerel Flint Scatter Area, Folio number TR0215 (Building Heritage). This does not present a conflict.
Restricting conditions	High-tide and wet conditions will make this site impossible to access. Also, the path is overgrown and needs to be maintained.
Nature of exposure(s)	Shoreline crags and cliffs

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	L'Étacquerel Fort, an outstanding example of an early-19th-century fortification (HER Number 1200183; Listed building TR0183). L'Étacquerel Lithic Scatter, an important lithic (flint) assemblage, has been collected from this site (HER Number 1200215; Listed place TR0215). Flint scraper (HER Number 1200284). La Tourelle is an unusual late Victorian Gothic building that retains its external character and contributes to its coastal setting (HER Number 1200130; Listed building TR0130). Field name, La Petite Houguette (HER Number 1200182; AAP TR0221).
Aesthetic landscape	This site is part of a bay with outstanding natural beauty.
History of Earth science	None
Economic geology	None

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy	National	Good	Detailed studies	
Sedimentology	National	Good	Detailed studies	X
Igneous/mineral/meta	Regional	Moderately good		
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The site is the best place to see unconformable contact between the *Rozel Conglomerate Formation* and the ignimbrites of the Bouley Bay Rhyolite Formation, with its deeply eroded top surface. The Bouley Bay Rhyolite Formation exposed here is a great place to examine spherulites. This is also one of the best places to see, in close proximity, many of the facies developed in the *Rozel Conglomerate Formation* and to consider the morphology of river channels in an environment that existed before the evolution of plants and soils, which had a profound impact on how rivers behave.

Assessment of Site: Current Site Usage	
Community	This site appears to be only minimally used by the public at the moment but could be interesting for walkers and holiday makers if access was improved.
Education	This is one of Jersey's most famous geology field trip localities and has been the location of many studies. It is a great place to teach

	students about climate change, as the *Rozel Conglomerate Formation* was deposited before the evolution of the plants and soils that we have today.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Geo-vandalism
Potential use	This site is useful for researchers and school education. It could be included in geological guides and have an interpretation panel or be incorporated into a geotrail.

Site Photos:

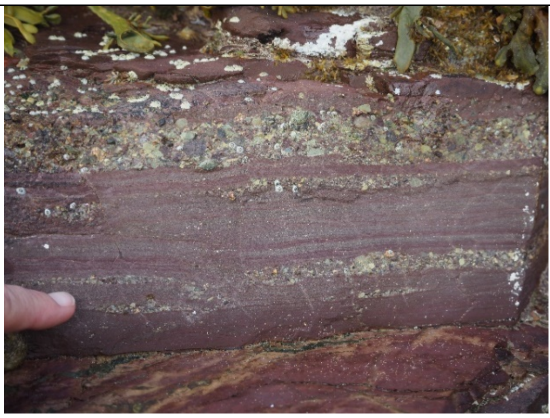
Photo 1: General view of the bay beneath La Tête des Hougues, facing north-north-east. BGS © UKRI 2020.

Photo 2: View into the bay beneath La Tête des Hougues, facing north-north-east, showing the *Rozel Conglomerate Formation* in the high cliffs and the shoreline to the left of the picture. The *Bouley Rhyolite Formation* is exposed beneath it, in the centre of the bay. BGS © UKRI 2020.

Photo 3: Angular clasts of rhyolite at the top of the *Bouley Rhyolite Formation*. These deposits are interpreted screes shed from topographic highs in an exhumed topography at the top of the ignimbrite. BGS © UKRI 2020.

Photo 4: Examples of 10-cm-scale spherulites from the cove at La Tête des Hougues. These are among the largest of these features seen at this locality. Radial fabrics are visible in some. BGS © UKRI 2020.

Photo 5: Examples of mm-scale spherulites from the cove at La Tête des Hougues. These are amongst the smallest of these features seen at this locality. BGS © UKRI 2020.

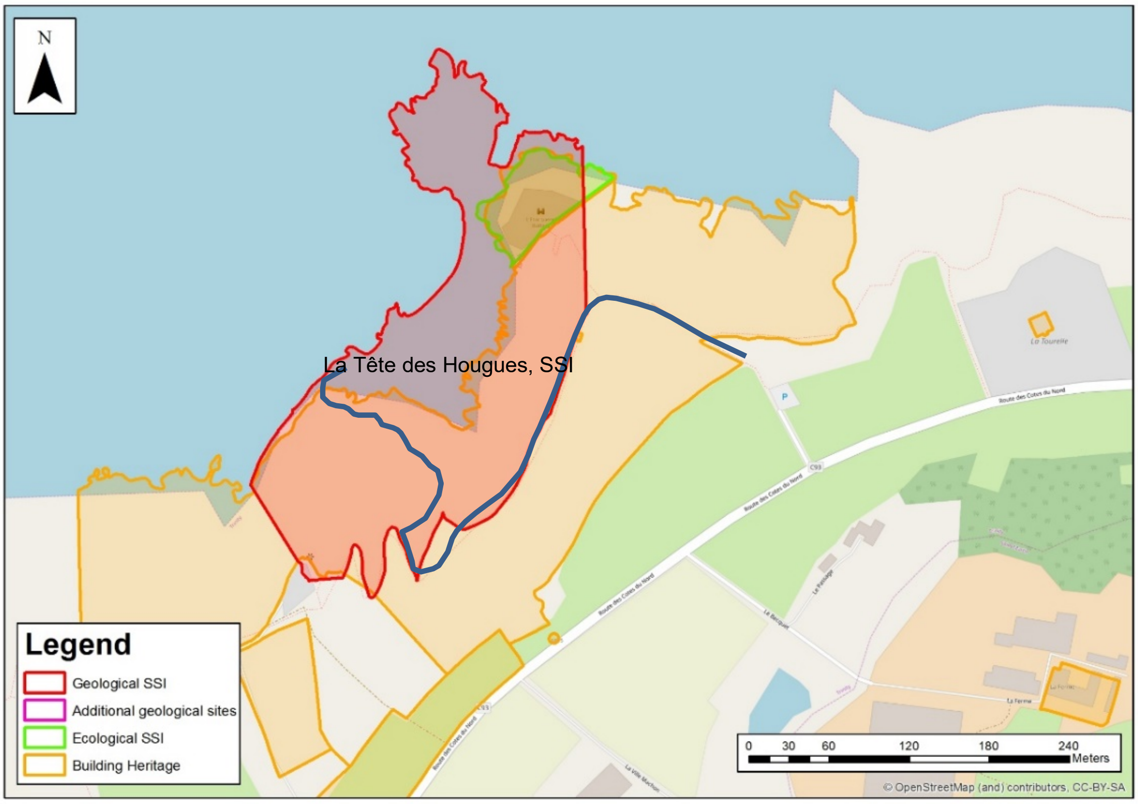


Photos 6 (left) and 7 (right): Directly overlying and interfingering the rhyolite breccia in the centre of the cove is an upwards-coarsening sequence of red silty sandstones and fine pebble conglomerate. These deposits include ripple cross lamination, and parallel and wavy lamination. Bedding surfaces show desiccation cracks, pebble imprints and load structures. These are interpreted as being deposited by low-energy streams (Went *et al.*, 1988). BGS © UKRI 2020.

Photo 8: An example of the channel filling, coarse conglomerates described by Went *et al.* (1988). These conglomerates form an upwards-fining sequence 28 m thick in the north-west part of the cove. This view shows m-scale imbricated clasts in a deeply incised channel. These deposits are interpreted as debris flows. BGS © UKRI 2020.

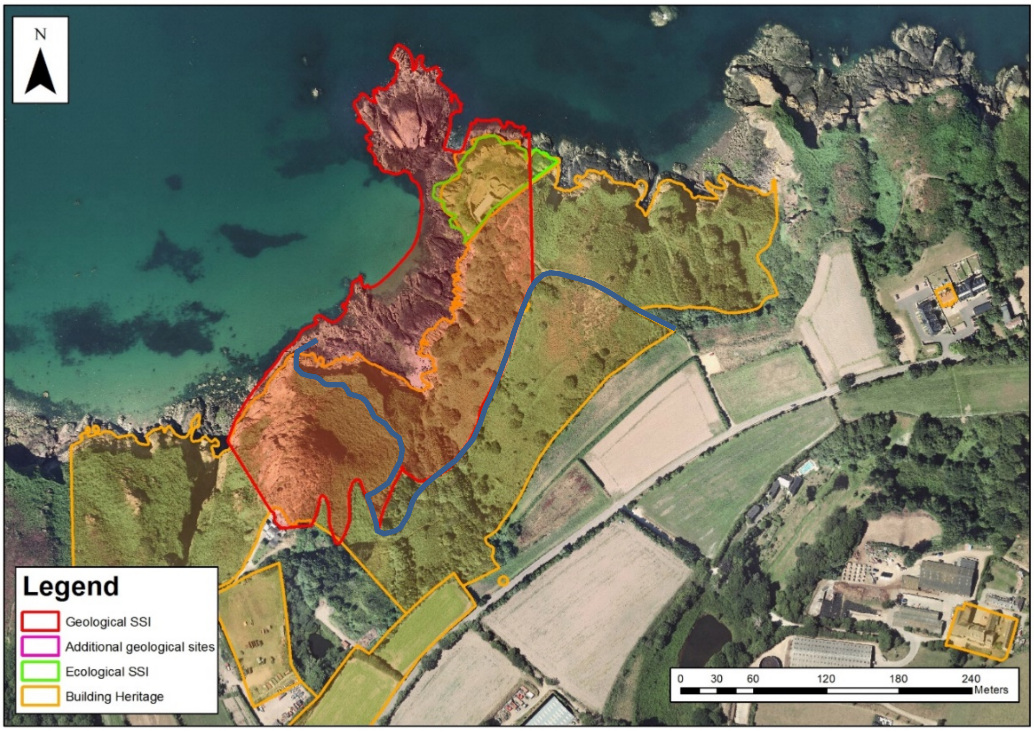
Photo 9: Small cores made by a geologist; this is an example of geo-vandalism. BGS © UKRI 2020.

Map of the site boundary on a topographic base



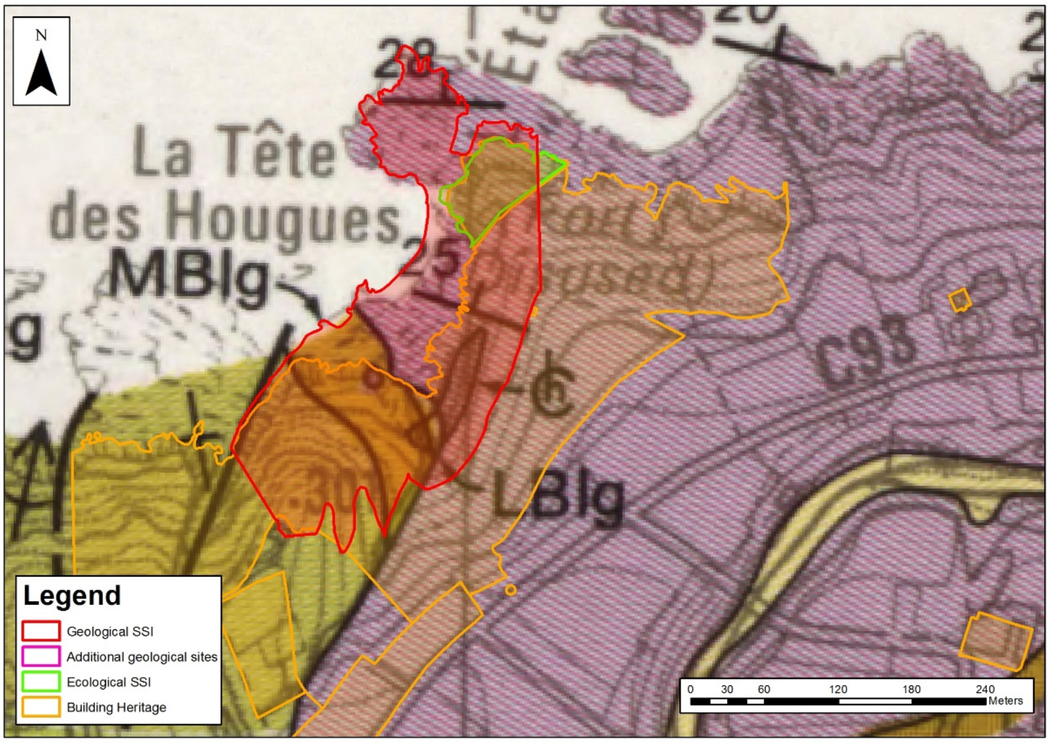
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA. Path to outcrop is shown by blue line.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey. Path to outcrop is shown by blue line.

Map of the site boundary on a published geological map



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.13 SITE NAME: LA SOLITUDE FARM, SSI

Site Information:

This site is a roadside cutting along the Rue de la Solitude, west of St Catherine's Bay. An atypical part of the *Rozel Conglomerate Formation* is exposed here; it comprises a weathered conglomerate with lithic sandstone lenses that is thought to represent a palaeo-weathered surface on an abandoned segment of an alluvial fan. The mudstone bands seen here are thought to have been deposited in a marginal lake; this is rare throughout the rest of the formation. More typical examples of the formation can be seen at the La Tête des Hougues SSI and the quarries at St Catherine's Breakwater and Tour de Rozel. The alluvial fan has a source area to the north of Jersey and is a great example of a river developed before the existence of land plants, whose evolution and associated soil development had a profound impact on the morphology of river systems.

National Grid Reference: Mid-point: 47323, 68898 West end: 47266, 68903 East end: 47378, 68909	**Site Type:** Artificial section
Site Ownership: Private	**Current Use:** Urban
Field Surveyors: RS Kendall and S Arkley	**Current Geological Designations:** Geological SSI
Date Visited: 25 September 2019	**Other Known Designations:** None

Site Map

Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Upper Cambrian to Ordovician	**Formation:** *Rozel Conglomerate Formation*
Rock Types: Sandstones and mudstones	

Site Description:

Introduction

This site is a roadside cutting along the Rue de la Solitude, west of St Catherine's Bay. This site is important because it exposes an atypical part of the *Rozel Conglomerate Formation* that comprises a weathered conglomerate with lithic sandstone lenses; it is thought to represent a palaeo-weathered surface on an abandoned segment of an alluvial fan. The mudstone bands seen here are thought to be the deposits of a marginal playa lake, which is a rare feature in the rest of the formation. More typical examples of the formation can be seen at the La Tête des Hougues SSI, Tour de Rozel and the quarries at St Catherine's Breakwater.

Prior to the evolution and large-scale distribution of land plants, rivers, such as the one that deposited the *Rozel Conglomerate Formation*, typically deposited relatively coarse sediments with very little mud in self-formed channels dominated by broad sheets of trough cross-bed (sheet-braid style) sediments. Land plants (embryophytes) enhance upland weathering and the production of fine-grained sediments, which are deposited in floodplains. Plant roots also contribute to the stabilisation of the banks of river channels, and so after land plants become well established, rivers also take on a more meandering style (Davies and Gibling, 2011).

Bedrock Units

Rozel Conglomerate Formation

The *Rozel Conglomerate Formation* typically comprises coarse, alluvial fan conglomerates, but here at La Solitude Farm, there are examples of tabular-bedded mudstones and fine-grained sandstone. These sediments are interpreted as representing deposition in a sandflat or lake environment at the fan toe (Went and Andrews, 1990).

At La Solitude Farm, the rocks are interpreted as an abandonment surface mantled in weathered material within a section of an alluvial fan. Within the section exposed here is a bed of purple mudstone, about 40 cm thick and at least 50 cm in lateral extent, in an exposure otherwise dominated by conglomerate. Beneath the mudstone bed, the conglomerate is friable and has a weathered appearance and thin sandstone lenses, which are also crumbly and contain lithic rather than quartz grains (Went, 2005).

The weathered conglomerate with lithic fragments (Photo 5) is thought to represent a mantle of weathered and partly reworked sediments in an abandoned section of the lower part of an alluvial fan. The overlying mudstone (Photo 3) was deposited in lake environments, indicating the inundation of the fan by a lake. These rocks are at or very near the base of the *Rozel Conglomerate Formation*, which is consistent with a distal fan location. As the fan developed and grew, these deposits became buried at the base of the formation (Went, 2005).

Lower Palaeozoic terrestrial sequences such as the *Rozel Conglomerate Formation* also occur in Alderney (Alderney Sandstone Formation) and northern Brittany (Erquy-Fréhel Group) and are thought to have developed during the early Palaeozoic; they are probably related to a phase of post-Cadomian rifting and subsequent molasses deposition, perhaps in response to the uplift and subaerial exposure of the Cadomian belt during the Cambrian (Went, 1991).

The *Rozel Conglomerate Formation* is the youngest of the sedimentary hard rock formations in Jersey (Bishop *et al*., 1989); its actual age is uncertain, but it is thought to have been deposited in the late Cambrian to Early Ordovician. Went and Andrews (1990) suggest that the *Rozel Conglomerate Formation* was likely deposited in the later stages of the Cadomian Orogeny.

Miller *et al*. (2001), however, link the deposition of the *Rozel Conglomerate Formation* to deposition in minor extensional basins associated with plutonism, which they date to *c.* 480 Ma (mid-Ordovician). Adams (1976) gave a date of 427 ± 13 Ma (recalculated as 435 ± 13 Ma) for a dyke that intrudes conglomerates at La Coupe Point; this date could provide a minimum age.

Structures

Although it is not apparent at La Solitude Farm, the *Rozel Conglomerate Formation* is folded into a WNW-trending syncline. The syncline has a sinuous axial trace that runs just south of the coastline between Tour de Rozel and Fliquet Bay; this is due to the open NE-trending folds that are superimposed on the main axis.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	There is ample on-street parking for cars adjacent to the site on Rue de la Solitude. The lane, however, is narrow and winding, so it is probably unsuitable for larger coaches.
Safety of access	This site is a roadside exposure so care should be taken in watching for traffic when examining the section.
Safety of exposure(s)	The exposure itself is relatively safe, with overhanging rock, and an examination of the exposure can be made while standing on a tarmac road. Care should be taken, as traffic may try and squeeze past on this narrow road.
Access	No access restrictions
Current condition	The sections are presently clear of vegetation but could benefit from cleaning to remove loose debris and moss.
Current conflicting activities	None
Restricting conditions	Cars parked along the side of the road in front of the section will limit access and visibility.
Nature of exposure(s)	This exposure is a roadside cutting.

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Site of menhir recorded by Stevens, C. and Stevens, M. (1986). A prehistoric menhir (recycled) adjacent to the east wing of the cottage is referenced in Rodwell (1996), although this was thought to have been moved or lost when the wing was demolished following the 1987 gales (HER Number 0700291). La Solitude Cottages and Swallow Cottage are a row of mid-19th-century cottages retaining their historic character and forming a picturesque grouping in a coastal valley setting. Properties at the location shown on 1849 Godfray Map (HER Number 0700120; Listed building MN0120).
Aesthetic landscape	None
History of Earth science	None
Economic geology	None

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy	Regional	Good	Detailed studies	
Sedimentology	National	Good	Detailed studies	X
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The value of this site lies in the easy access it provides to the oldest section of the *Rozel Conglomerate Formation*. This formation typically comprises coarse alluvial fan conglomerates, but here, it consists of mudstone and fine-grained sandstone, which are interpreted as having been deposited in temporary shallow pools and more permanent lakes at the toe of the alluvial fan. This makes this site important for understanding these parts of a pre-vegetation alluvial fan system.

Assessment of Site: Current Site Usage	
Community	This site is presently unused.
Education	This site is an excellent resource for the study of lake deposits accumulating in abandoned parts of alluvial fans. It is also an interesting place to examine the deposits of a river that existed before the evolution of land plants, which had a profound effect on channel architecture later in geological time.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	This site is vulnerable to natural overgrowth and weathering.
Potential use	The site has the potential for research and education at all levels and could form part of a geotrail about the *Rozel Conglomerate Formation* and pre-vegetation rivers.

Site Photos:

Photo 1: General view of roadside section, facing west. BGS © UKRI 2020.

Photo 2: General view of roadside section, facing east. BGS © UKRI 2020.

Photo 3: A view, facing north, of purple mudstone with conglomerate above and below. BGS © UKRI 2020.

Photo 4: Tabular-bedded, and in this case, parallel-laminated sandstone and mudstone deposited by sheet flows or from suspension in standing pools of water. Thicker intervals of structureless clay-dominated mudstone are interpreted as having been deposited in more well-established lakes. BGS © UKRI 2020.

Photo 5: Weathered conglomerate beneath the mudstone bed with horizons of thin purple sandstone lenses. This is interpreted as weathered and partly reworked debris on an abandoned section of the alluvial fan. BGS © UKRI 2020.

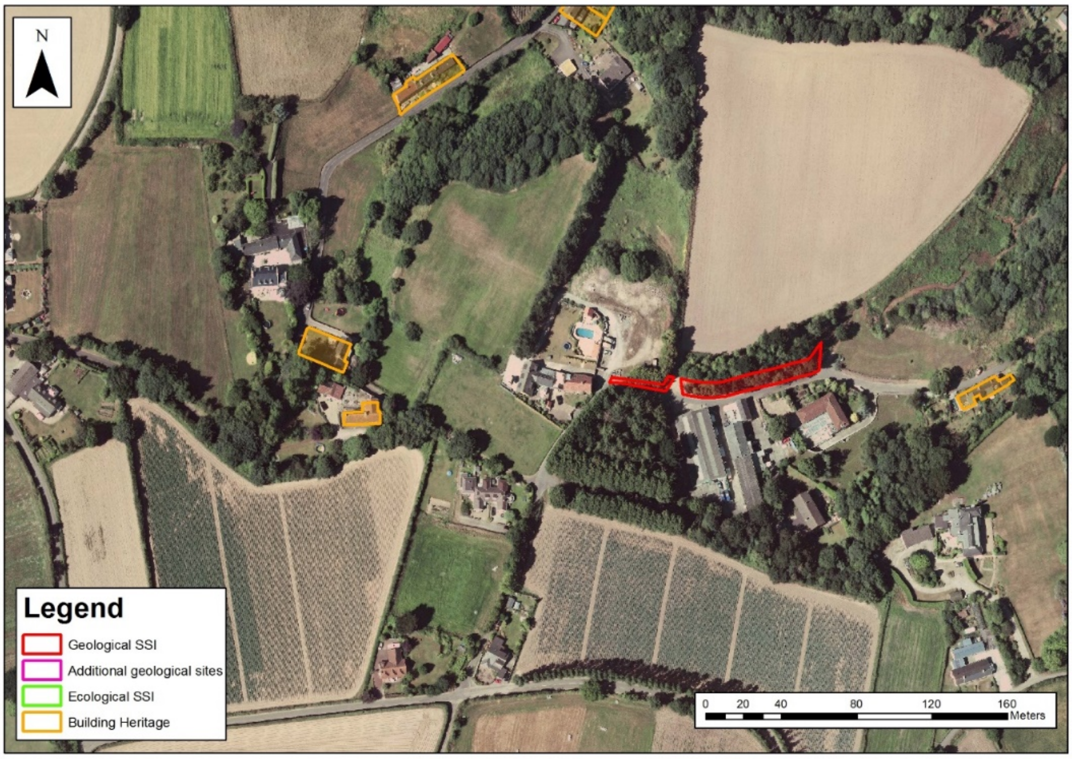
Photo 6: The conglomerate above the purple mudstones and sandstones is moderately to poorly sorted and pebble grade. Here, there is crude subhorizontal stratification, forming low-amplitude troughs. BGS © UKRI 2020.

Photo 7: Minor extensional faulting in the western part of the section, picked out by the displaced sandstone layer. BGS © UKRI 2020.

Map of the site boundary on a topographic base

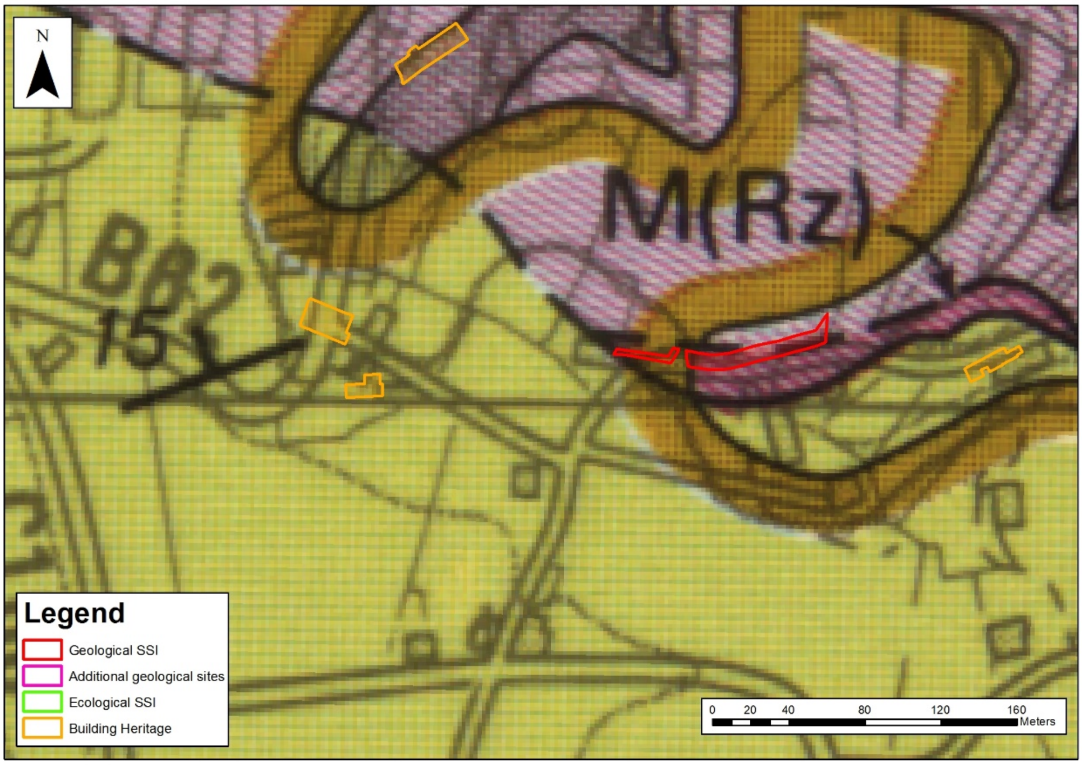
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

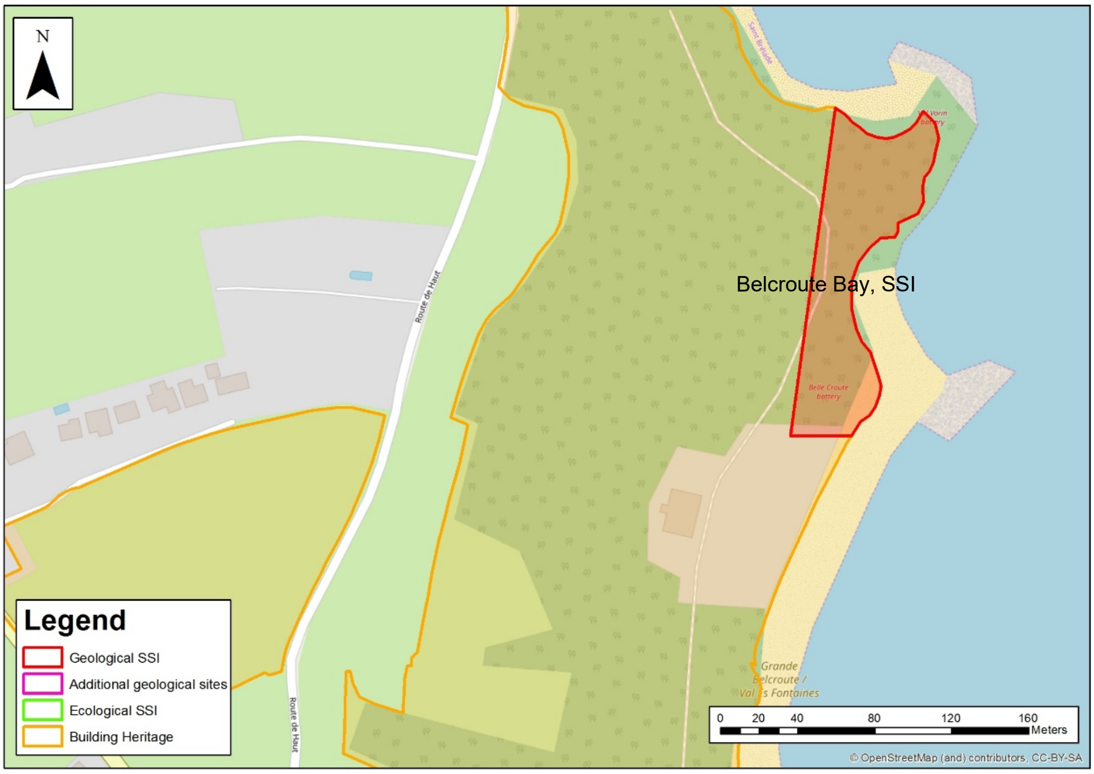


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.14 SITE NAME: BELCROUTE, SSI

Site Information:	
The Belcroute site consists of a series of small inlets, separated by rocky headlands, located to the south of St Aubin Harbour. The inlets are backed by cliffs, which reveal sections through a sequence of Quaternary sediments. These deposits are reported to span two warm stages with high sea levels and at least two cold stages, with this complex palaeoenvironmental/climate record providing the primary reason for the SSI designation of the Belcroute Bay site.	
National Grid Reference: Mid-point: 37577, 65196/49.181, -2.168 North end: 37523, 65208/49.182, -2.169 South end: 37531, 65038/49.178, -2.169	**Site type:** Natural cliff section and exposures
Site Ownership: Part private and part public	**Current Use:** Open country, coastal
Field Surveyors: J Everest and L Hughes	**Current Geological Designations:** Geological SSI
Date Visited: 24 September 2019	**Other Designations:** The site boundary is within the larger 'Potential Listed Building Grade 2' area of Noirmont Manor.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Pleistocene	**Formation:** Loess
Rock Types: Silt or fine sand	
Age: Pleistocene	**Formation:** Beach
Rock Types: Gravels and cobbles, often rounded	
Age: Pleistocene	**Formation:** Head
Rock Types: Gravels and cobbles, often angular	
Age: Precambrian (Ediacaran)	**Formation:** *South-west igneous complex* (Corbière granite)
Rock Types: Granite	
Age: Precambrian (Ediacaran)	**Formation:** *Jersey Shale Formation*
Rock Types: Sandstone, siltstone and claystone with rare intra-formational conglomerates	

Site Description:

Introduction

The site at Belcroute occurs at the southern end of the bay and can be accessed from the Royal Channel Islands Yacht Club. The site is dominated by a *c.* 300-m-long outcrop of sedimentary rocks belonging to the *Jersey Shale Formation*; they are overlain by *c.* 7 to 8 m of Quaternary sediments comprising head, loess and beach deposits. The angular stony head that directly overlies and incorporates clasts of the bedrock *Jersey Shale Formation* is exposed *c.* 1 m above MHWS on a small headland at the northernmost end of the outcrop. Isolated pockets of a consolidated mud have been locally observed within hollows on the bedrock surface. These muds have been found to contain sub-Arctic pollen and insects, with potential ages of 186 ka BP or older. This marine beach deposit, possibly Ipswichian in age, is in turn overlain by blown sand, head and loess, with this upper part of the Quaternary sequence recording dynamic environmental change throughout the Devensian (Weichselian). The site is important because the deposition of these sediments spans two warm stages with high sea levels and at least two intervening cold stages, placing the Belcroute Bay site in Jersey within the broader context of the Quaternary history of the wider Channel region and North-west Europe.

Bedrock Units

Jersey Shale Formation

The bedrock exposed in Belcroute immediately to the south of the Yacht Club largely comprises sedimentary rocks belonging to the *Jersey Shale Formation*. However, at the southern end of the bay, these sedimentary rocks are replaced by Corbière granite, a component of the *South-west igneous complex*. To the south of the rocky promontory that extends out to St Aubin's Fort, the *Jersey Shale Formation* is cut by an approximately E–W-trending flow-banded rhyolite dyke (Bishop *et al*., 2003, marked 'F' on the accompanying geological map). A detailed sedimentological study by Helm and Pickering (1985) identified six individual sedimentary facies within the *Jersey Shale Formation*, which they grouped into four facies associations that record deposition within different parts of a submarine turbidite fan environment. Helm and Pickering (1985) thought that the predominantly fine-grained sandstones, siltstone and mudstones exposed at Belcroute Bay were deposited in the lower and outer (distal) parts of the fan system. Plate tectonic reconstructions published by Dewey (1969) and Mitchell and Reading (1971) argue that this turbidite fan system was perched on the continental slope adjacent to a volcanic island arc above a subduction zone.

In the southern part of Belcroute, the sedimentary rocks of the *Jersey Shale Formation* are harder and possess a purplish colouration on fresh surfaces, possibly as a result of contact metamorphism associated with the emplacement of the Corbière granite. The grey-coloured Corbière granite exposed in the southern part of the bay is finer grained than elsewhere within the *South-west igneous complex*, leading Bishop *et al*. (2003) to suggest that there is a chilled margin against the host sedimentary rocks. However, the actual intrusive contact between the granite and the *Jersey Shale Formation* is obscured beneath the younger head deposits. The *South-west igneous complex* is one of three major intrusion complexes in Jersey. On the published geological map (IGS, 1982), the *South-west igneous complex* comprises a single concentrically zoned granitic pluton, which is divided into three main components: (i) a wide outer zone of granite known as Corbière granite, which comprises K-feldspar megacrysts in a finer grained groundmass; (ii) a *c.* 250-m-wide middle zone known as La Moye granite; and (iii) a small central zone referred to as St Brelade granite.

Quaternary Sediments

At the northern end of the exposure, preserved in hollows within the bedrock surface, there are isolated pockets of a dark brown marine deposit. Keen *et al*. (1996) argue that these sediments were probably deposited low in a shore zone environment (most likely during MIS 7; 245–186 ka BP) and were then subaerially exposed as a result of a fall in sea level and subjected to pedogenesis (soil forming processes). The marine deposit is immediately overlain by a coarsely bedded head deposit composed of angular, locally derived clasts of the *Jersey Shale Formation*. The head is in turn overlain by *c.* 0.5 m of grey-yellow clayey loess, which exhibits a faint layering that was interpreted by Keen *et al*. (1996) as providing evidence of two phases of soil formation. Based on a proposed correlation of the lower units of head and loess at Belcroute with comparable deposits occupying a similar stratigraphic position at La Cotte de St Brelade, the lower part of the Quaternary sequence at this site is considered to most likely be from MIS 6 (186–128 ka BP).

The top of the loess is truncated by a marked erosion surface, which is immediately overlain by a second marine deposit (up to 1 m thick) comprising rounded pebbles and cobbles of granite, as well as boulders of sandstone. This clast-supported gravel possesses a sandy matrix that is largely composed of detrital quartz and feldspar, indicating that it was mainly derived from a granite source. This gravel is the uppermost 'marine' unit in the Quaternary sequence at Belcroute, suggesting that it most likely dates from MIS 5e (*c.* 121 ka BP), making it compatible with similar-aged deposits at Belle Hougue; it occupies a stratigraphic position similar to that of marine deposits observed at the Portelet, Bonne Nuit and Bouley Bay in Jersey and elsewhere within the wider Channel region. Large cobble beaches with individual cobbles in excess of 15 cm across, which occur around the low tide level, also support this MIS 5e age (information from J Renouf).

Overlying this upper marine unit at Belcroute is a relatively thick (up to 5 m thick) sequence of windblown sand, which coarsens upwards into sandy head. These units are thought to contain several phases of soil formation, with the uppermost soil horizon showing clear evidence of frost creep. Keen *et al*. (1996) argue that this provides evidence of climatic cooling during MIS 5, and they have suggested that the uppermost part of the sequence at Belcroute can be correlated with similar deposits in Normandy, Brittany and the Cotentin from the Brørup Interstadial (warm period) in MIS 5c (96–87 ka BP). Above the sandy head at Belcroute is a further unit of crudely stratified head (up to 12 m thick) containing large bedrock fragments and displaying evidence of three soil-forming periods. Keen *et al*. (1996) suggest that this upper head deposit is no younger than Early Devensian (116–59 ka BP) in age and can be correlated with the upper deposits at La Cotte de St Brelade. At the top of the Quaternary sequence at Belcroute is a *c.* 3-m-thick unit of sandy loess containing variable amounts of clay, possibly indicating that it was deposited by overland flow as a result of seasonal snow melt. This pattern in the upper loess is seen across much of Normandy and is correlated with the 'Kesselt' horizon identified in Belgium and elsewhere in North-west Europe, which has been dated to *c.* 26 ka BP.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Paid parking is available at the Royal Channel Islands Yacht Club in the southern part of St Aubin, a short distance away from the beach.
Safety of access	It is slippery on the rocks and there is the potential to be cut off by the tide. Some steps are missing.
Safety of exposure(s)	Some upper parts of the section are loose and overhanging, with sections of material held in place with vegetation.
Access	Access to the outcrop exposures and Quaternary sections is along the pier wall, along the beach to the peninsula and up some tarmac steps to the section. The Quaternary section can also be seen in the small cove, close to the cliff.
Current condition	The section is actively eroding and fresh, with some small sections obscured by vegetation.
Current conflicting activities	There were bees nesting in the sandy part of the upper section. No trowel clearing should be done until the area is checked for bee larvae.
Restricting conditions	The outcrop may not be accessed at high tide.
Nature of exposure(s)	Natural section

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Noirmont Manor is an important manor house site associated with the fief of Noirmont; the history of the site dates back to the 14th century (HER Number 0100107; Listed building BR0107).
Aesthetic landscape	Located on an east-facing coastal embayment next to St Aubin's harbour
History of Earth science	None known
Economic geology	None known

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology	Regional/ international	Good	Detailed studies	X
Igneous/mineral/meta	Local	Moderately good	Descriptions	
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The site is valuable because it contains examples of the coastal geomorphology of coastal erosion and Quaternary sediments and environments.

Assessment of Site: Current Site Usage	
Community	Dog walking, beach activities
Education	Accessible to children and adults with good mobility if care is taken

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The intertidal areas are subject to high-energy weathering and erosion, but this also helps to keep the exposures clear of vegetation and to display geological features clearly.
Potential use	This site could be used as part of a geotrail or for school trips and higher education and research.

Site Photos:

Photo 1: View of the southern, thicker Belcroute Bay section, incorporating the complete sequence described here. BGS © UKRI 2020.

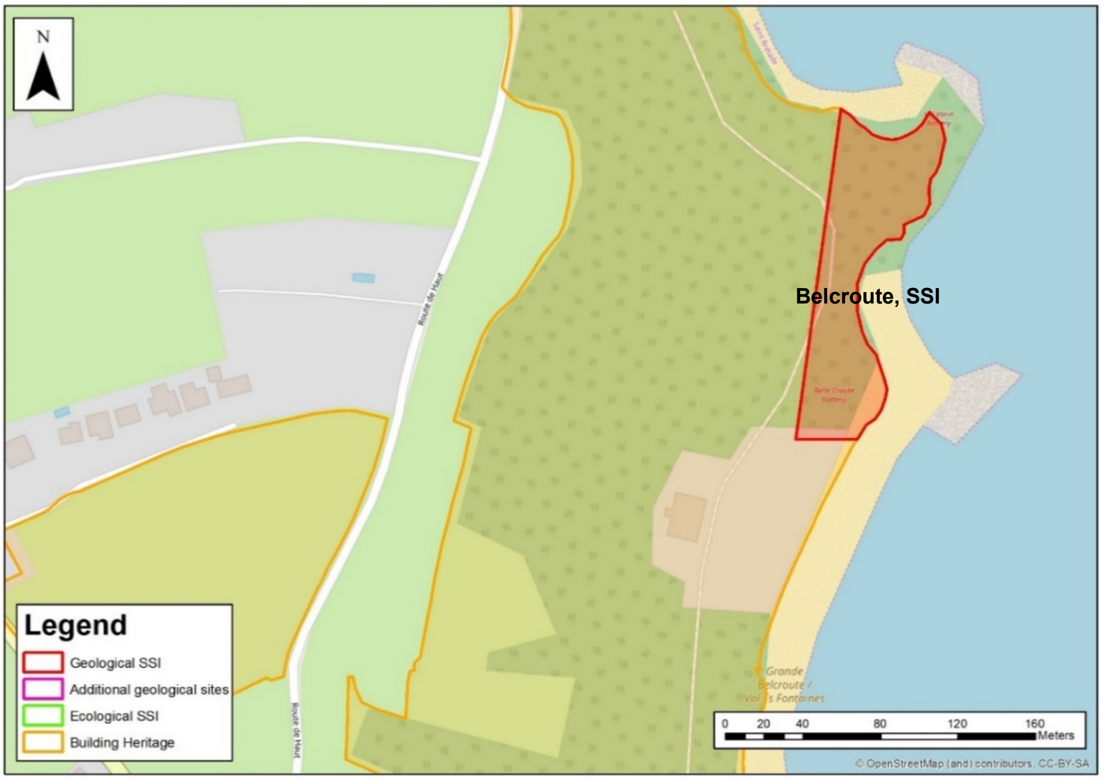
Photo 2: Disaggregated *Jersey Shale Formation* bedrock and lower head unit in the northern outcrop looking west. BGS © UKRI 2020.

Photo 3: Close-up view of bands of the lower head unit mantling the *Jersey Shale Formation* bedrock. BGS © UKRI 2020.

Photo 4: View of the northern outcrop looking north towards St Aubin. The lower loess unit can be seen overlying the lower head unit. BGS © UKRI 2020.

Photo 5: Close-up view of the disaggregated *Jersey Shale Formation* bedrock with the overlying lower head unit. BGS © UKRI 2020.

Map of the site boundary on a topographic base



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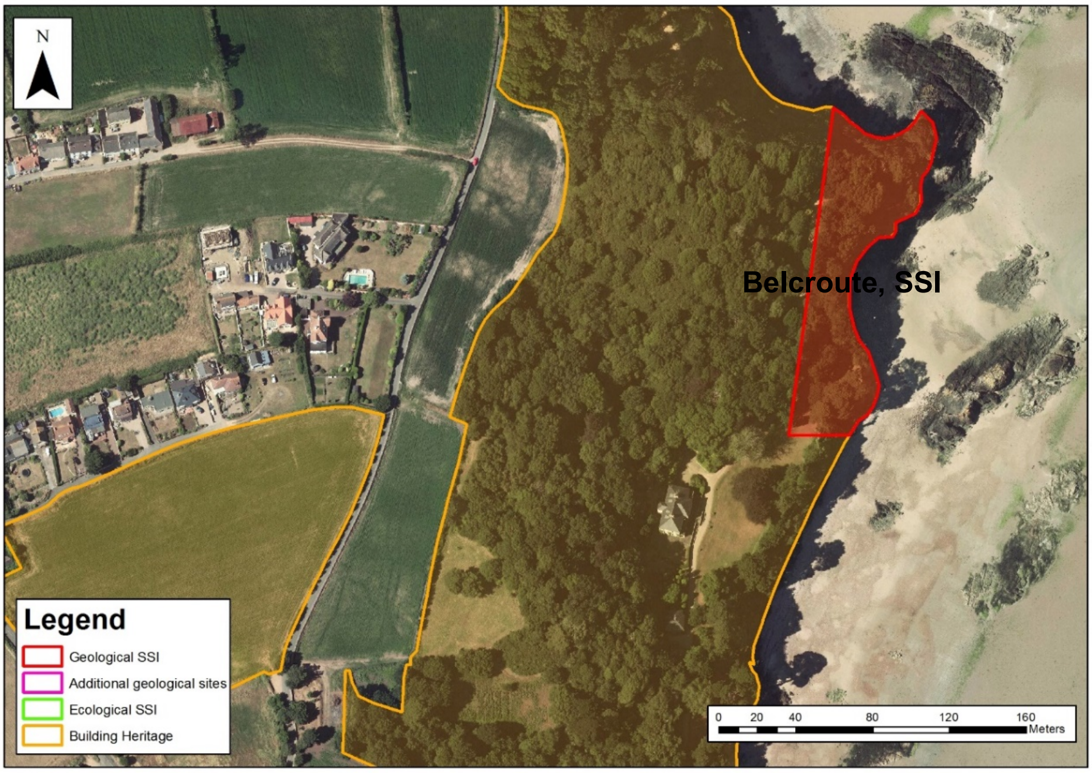
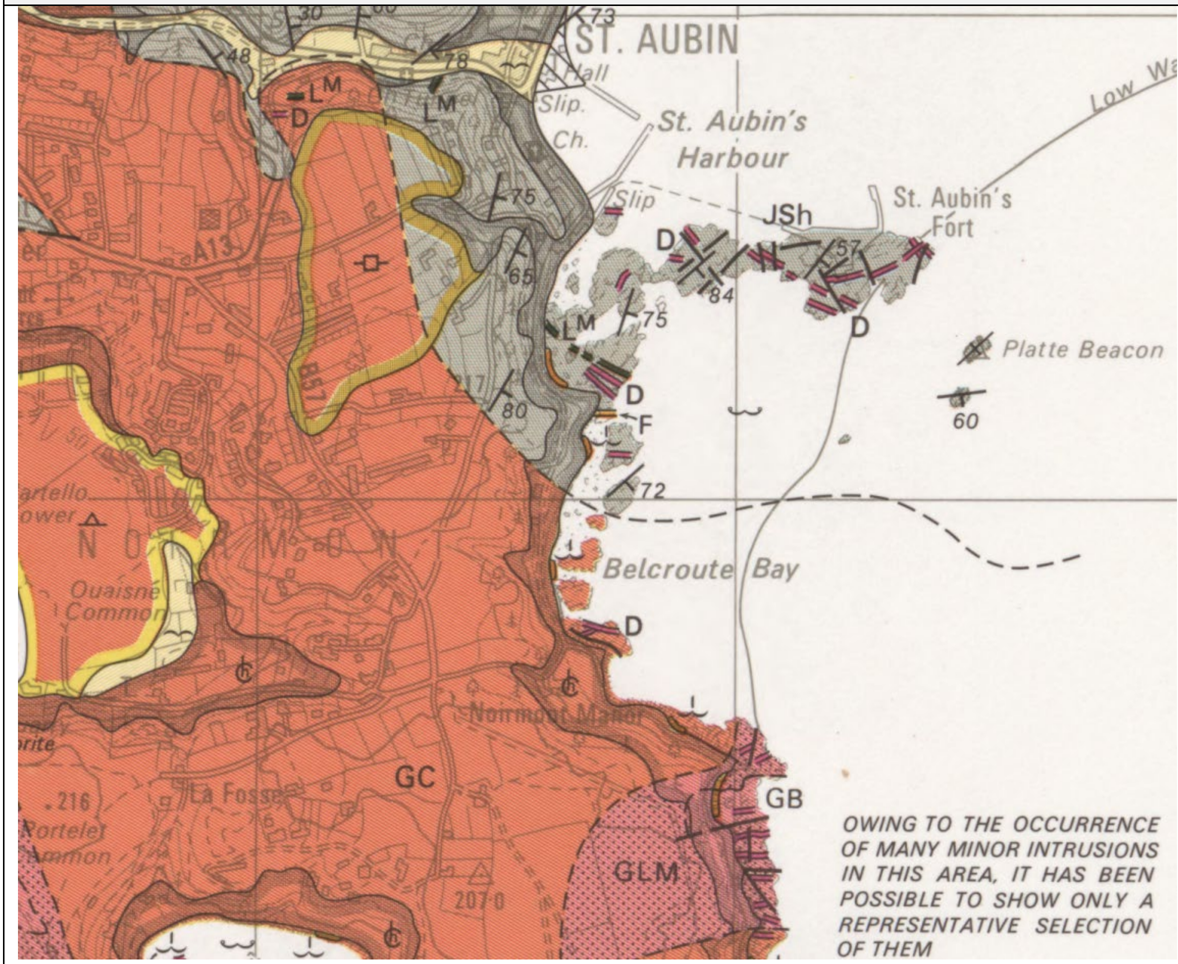
Map of the site boundary on an aerial photograph



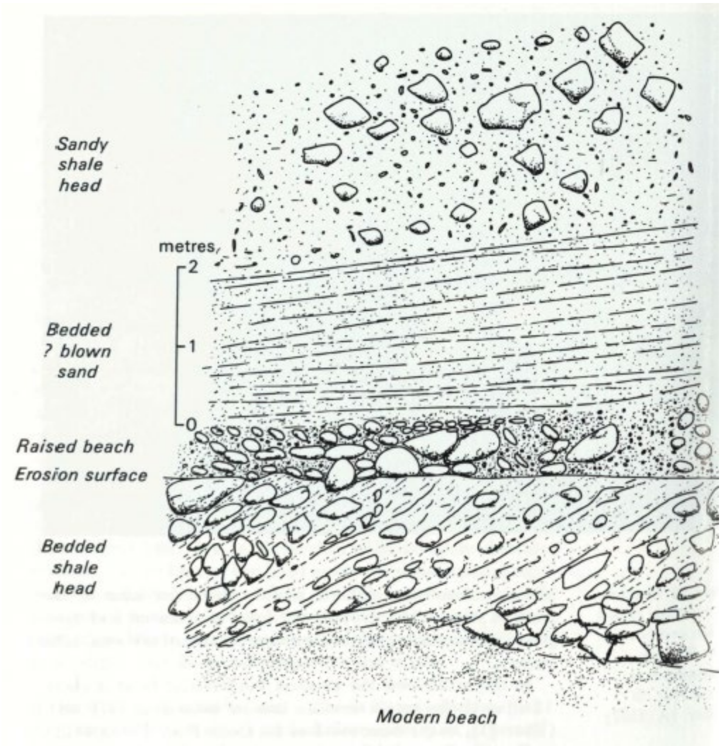
Imagery ©2020 Government of Jersey.

Published geological map of the site



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

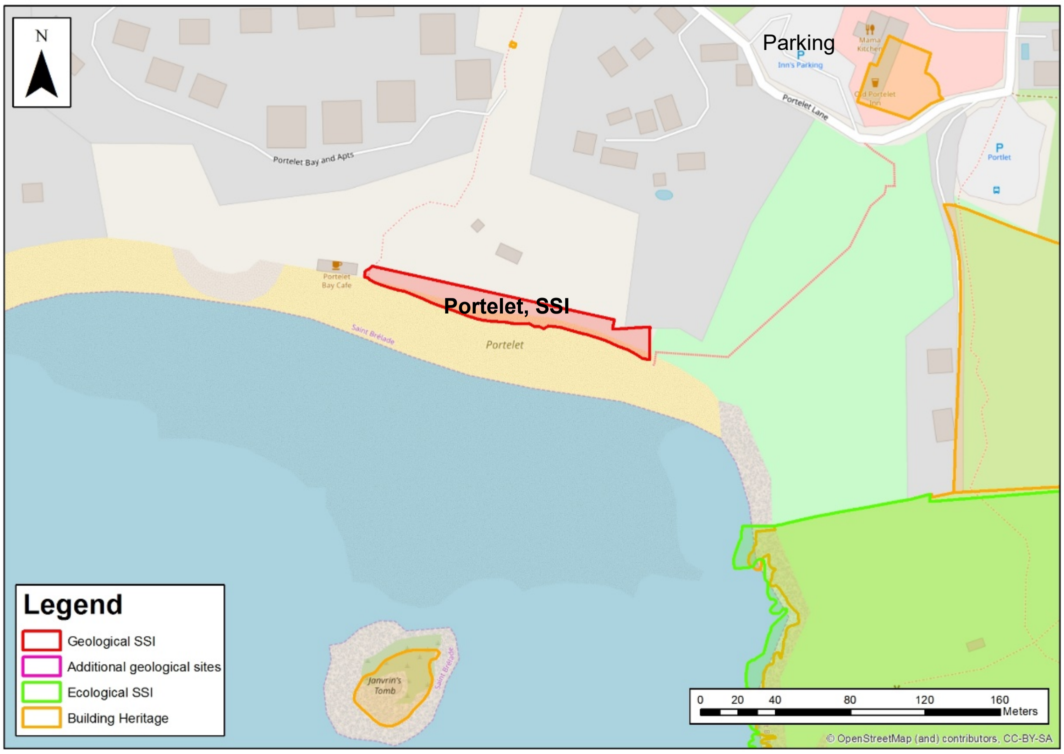
Sketch section of the drift deposits at Belcroute, St Aubin's Bay (Bishop and Bisson, 1989)



7.15 SITE NAME: PORTELET, SSI

Site Information:	
Portelet is a south-facing crescentic bay whose 70-m-long central exposed cliff section already has an SSI designation. The cliff sections are capped by blown sand deposits from the Early Devensian period. The cliff exposure provides possibly the best exposure of Middle and Late Quaternary sediments on the Island; it comprises basal head deposits, including coarse marine sands, overlain by beach cobble and boulder beds, which are in turn overlain by dune sands and head and capped by loess. The entire sequence most likely spans the period from *c.* 245 ka BP to *c.* 60 ka BP. The site is important because this sequence spans two warm stages with high sea levels and at least two cold stages.	
National Grid Reference: Mid-point: 36857.8, 64117.7 West end: 36475.8, 64063.7 East end: 37193.3, 64067.9	**Site type:** Natural section
Site Ownership: Private (multiple)	**Current Use:** Natural coastline, some residential development and landscaping above the site
Field Surveyors: J Everest and L Hughes	**Current Geological Designations:** Geological SSI
Date Visited: 24 September 2019	**Other Designations:** None known

Site Map



Stratigraphy and Rock Types:	
Age: Pleistocene	**Formation:** Head
Rock Types: Cobbly, gravelly	
Age: Pleistocene	**Formation:** Dune sand / loess
Rock Types: Fine sand and silt	
Age: Pleistocene	**Formation:** Beach
Rock Types: Cobbly, bouldery, pebbly	
Age: Ediacaran (Latest Precambrian)	**Formation:** *South-west igneous complex*
Rock Types: Coarse-grained granite of the Corbière type	
Age: Ediacaran (Latest Precambrian)	**Formation:** Jersey Main Dyke Swarm
Rock Types: Most commonly dolerite	

Site Description:

Introduction

Portelet is a crescentic, south-facing, rock-bounded bay with a sandy beach and central Island (Photo 1). It is very attractive and popular with tourists and locals. There is some housing development on the break of the slope into the bay to the north, adjacent to the Portelet Inn. This site is important for its exposures of Middle and Late Quaternary sediments.

Bedrock Units

South-west igneous complex

The granitic bedrock exposed at Portelet Bay forms part of the *South-west igneous complex*, one of three major intrusion complexes in Jersey. On the published geological map (IGS, 1982), the *South-west igneous complex* comprises a single concentrically zoned granitic pluton, which is divided into three main components: (i) a wide outer zone of granite known as Corbière granite, which comprises K-feldspar megacrysts in a finer-grained groundmass; (ii) a *c.* 250-m-wide middle zone known as La Moye granite; and (iii) a small central zone referred to as St Brelade's granite. The porphyritic Corbière granite underlies around 80% of the onshore outcrop at Portelet Bay. Also exposed in the bay are a number of sheet-like, E–W-trending dolerite dykes belonging to the Jersey Main Dyke Swarm.

Quaternary Sediments

Raised beaches

The evidence for past high relative sea levels is widespread in Jersey, Guernsey and Alderney, as well as on the Cotentin Peninsula and in Brittany. It includes wave-cut notches and platforms cut into the bedrock, as well as raised beach remnants, which occur at a wide range of elevations above the present mean sea level. Currently, six separate Quaternary high sea-level stands have been identified in Jersey, of which the 8 m raised beach is the most commonly exposed around the coastline. This raised beach forms easily identifiable features, which are particularly prominent at the Le Pulec (Renouf and James, 2011), Bonne Nuit, Bouley and Rozel bays in the north of the island, and Portelet and Belcroute in the south of Jersey (Keen, 1993 and Keen, *et al.*, 1996). Beach material is composed of a wide range of clast sizes, from 40 cm cobbles, such as those found at Portelet, to fine gravel and sand at Belcroute. The 8 m beach sediments often overlie head deposits, and this, combined with some of the few dates derived using both U-series and AAR methods from the raised beach at Belle Hougue, has led Renouf and James (2011) to assign the 8 m beach an age of *c.* 121 ka BP, which correlates well with the wider Ipswichian/Eemian Period across Europe (Figure 2). This proposed age is in contrast to the previously favoured MIS 7 age postulated for these features across Jersey; they were thought to have formed between 245 and 186 ka BP (e.g., Keen, 1993). Without an extensive dating programme of these features, possibly using more modern applications (e.g., revised ^{14}C, thermoluminescence, terrestrial cosmogenic nuclides), this chronology cannot be more tightly constrained, and these differences in interpretation will remain.

Terrestrial deposits: Loess

Loess, in the form of a structureless orange-brown silt, is widespread across Jersey and mantles *c.* 75% of the plateau surface of the Island. It is thickest around St Clement and on the plateau around La Hougue Bie, where it is reported to be up to *c.* 5 m thick. Elsewhere it is commonly less than 3 m thick, for example, in St Peter and St Ouen; from these locations, it progressively thins to the west (Keen, 1993). The silty loess deposits were transported by predominantly north-westerly (Lefort *et al.*, 2019) winds primarily during cold periods throughout the Quaternary. Although they most certainly pre-date the Holocene, the age of the loessic deposits does vary as in some areas: they are observed underlying Middle Pleistocene deposits, but elsewhere they rest on head of Late Pleistocene age. It is likely that the thickest loess deposits, found on the eastern part of the Island, are of Middle Quaternary age or older.

Terrestrial deposits: Head deposits

During cold climate conditions, repeated freezing and thawing causes the frost shattering, erosion and disaggregation of exposed bedrock surfaces. The gravitationally driven downslope movement of this broken material due to a combination of solifluction, gelifluction, debris flows and soil creep can lead to the accumulation of significant thicknesses of material at the bases of slopes. These deposits, termed 'head', are typically poorly sorted with little stratification, and their components range from boulders to silt; however, in some sequences coarse bedding can be observed. Head thicknesses can reach up to 20 m along the base of ancient abandoned (palaeo) coastal cliff lines. The height of the palaeo-cliff is directly related to the thickness of the head deposit, with a ratio of cliff height to head thickness of *c.* 4 or 5:1 (Keen, 1993).

Head deposits occur at many coastal locations across Jersey and have been observed forming fans and cones beneath the blown sand in the St Ouen's, St Aubin's and St Clement's bays. At Portelet and Belcroute, up to 2 m of head, directly overlying bedrock, can be seen beneath the gravels of the 8 m raised beach, leading to the assumption that these periglacial slope deposits are pre-Ipswichian in age. The thickest accumulations of head occur at the Bonne Nuit and Bouley Bay; these accumulations are up to *c.* 30 m thick.

Notable features (described in the site report)

At Bonne Nuit, the head exposed in the central and eastern parts of the bay also contains subhorizontal grey silt layers, possibly indicating deposition into a lagoon (Bishop and Bisson, 1989) that was isolated on the foreshore as a result of falling sea levels. At La Cotte de St Brelade, the head deposits contain faunal remains and anthropogenic artefacts, including the bones of mammoths, rhinoceros, rodents and birds, along with the tools and bones of Neanderthals; as a result, the site is of international archaeological significance. At Fliquet Bay, peat containing beetle and pollen taxa, indicative of formation in a sub-Arctic environment, has been incorporated into the base of the head deposits. An infinite ^{14}C age obtained for the peat (Coope *et al.*, 1980) has been used to suggest that the sequence is Ipswichian in age; however, recent advances in radiometric dating techniques may argue for a reinvestigation of the site.

Head also occurs in inland Jersey; however, these inland deposits tend to be thinner and mantle the lower valley slopes to maximum depths of 2–3 m. The inland head deposits also tend to be finer grained than those at the coast, because they are mainly derived from the loess on the plateau above.

The Quaternary sediments deposited against the granite cliffs at Portelet Bay are revealed in three wave-cut sections: there is one section in the far eastern part of the bay and one in the west, and the best exposure occurs in the central part of the bay at the foot of the steps from the Portelet Inn (Photo 2). This section runs behind the modern beach for *c.* 70 m and occurs within the 8 m raised beach sediments; it comprises well-exposed beach, head and loess deposits. This site was described by Keen *et al*. (1996), who suggest that it is one of the most important 8 m raised beach sites in the wider Channel region. Exposed at the base of the section, immediately above the modern beach, is 1–1.5 m of orange-brown silty loessic head with discontinuous lamination; it has what is called a *limon a doublets* texture (1–4 mm). This lamination is particularly well developed towards its upper boundary (Photo 3). The loessic head is overlain by a 0.5–1.5-m-thick unit of clast-supported boulder gravel, which possesses a loess matrix and an open clast framework. The gravel is interpreted as being part of the 8 m raised beach and is mainly composed of well-rounded granite boulders, which are typically between 0.3 and 0.6 m in size but can reach up to 1 m in length. The undulating/wavy upper boundary of the boulder gravel is overlain by a *c.* 1-m-thick unit of massive silty sand containing occasional angular clasts up to <0.2 m in length. This massive sand is in turn overlain by a *c.* 6-m-thick unit of stratified sandy silt, which contains occasional gravel beds (with individual clasts up to 2 cm in size), isolated angular clasts and rare beds of angular gravel. This sandy silt unit was possibly deposited by slope-wash processes. Keen *et al*. (1996) also reported that this unit contains evidence of frost action, which is indicative of periglacial conditions. The top of the section is capped by head, which comprises fine to medium pebbles, and above that is the loess.

A previously undescribed unit of consolidated grey-brown, clast-rich sandy mud exposed on the foreshore, immediately seaward of the western cliff section in Portelet (Photo 4), was recognised during this survey. The angular to well-rounded clasts contained within this mud are composed of shale, quartz and granite. Although the authors were not able to examine the clasts, Coope *et al*. (1986) (also see Keen, 1993) describe compositionally similar organic muds exposed on the foreshore at St Aubin's Bay (not examined during the present survey); they appear to occupy a stratigraphical setting similar to that of the muddy deposits at Portelet Bay. The St Aubin's Bay deposits are undated, but the flora and fauna they contain suggest that they were deposited during a cold stage, either during the Early Devensian (IOS stages 5a–d) or earlier, and they may potentially correlate with sites on the Cherbourg Peninsula in Normandy (Coope *et al*., 1986).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Parking is available in the car park by the Portelet Inn at the top of the cliff.
Safety of access	There are many well-maintained concrete steps with some handrails; they can be sandy towards the beach.
Safety of exposure(s)	High and overhanging outcrop in places
Access	Down the well-signed path from the car park
Current condition	Partly vegetated, actively eroding in places

Current conflicting activities	Some residential development on the raised beach
Restricting conditions	Tides, property development, sea defences
Nature of exposure(s)	Coastal cliff outcrop

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Low-level raised beach, which is important for the study of ancient sea levels and climate change (HER Number 0100120). Portelet Tower in the middle of the bay is a Martello-type tower built in 1808 (HER Number 0100105; Listed building BR0105).
Aesthetic landscape	Scenic location
History of Earth science	None known
Economic geology	None known

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology	Regional	Good	Interpretations	X
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology	Regional	Regional	Interpretations	X

Geoscientific Value of the Site
The site is of value for the study of the coastal geomorphology of coastal erosion and Quaternary sediments and environments. It has a regional correlation with other sites in Jersey and with sites across the wider Channel and Normandy region.

Assessment of Site: Current Site Usage	
Community	Dog walking, boating and beach activities
Education	Accessible to children and adults with good mobility if care is taken

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Encroaching vegetation
Potential use	Education, walks, information board

Site Photos:

Photo 1: View eastwards to Portelet Bay from Portelet Common. The main exposed section can be seen immediately to the rear of the sandy beach; it comprises sediments of the 8 m raised beach that are clearly identified in sections around the bay. BGS © UKRI 2020.

Photo 2: The most clearly exposed section within the 8 m raised beach shows distinct environmental changes and fluctuations in former sea levels. The raised beach deposit formed of rounded cobbles and boulders is well displayed in the lower cliff section. This is overlain by a massive sand bed that is *c.* 0.5–1 m thick; a laminated loess unit overlies this sand. This silty sand grades upwards into head, with interbeds of rare subangular gravel and cobble clasts. BGS © UKRI 2020.

Photo 3: Lowermost loessic unit in the central exposure, showing orange-brown silty loessic head with discontinuous well-developed laminations that have a *limon a doublets* texture (*c.* 1–4 mm thick). These are particularly obvious in the centre of the image below the upper contact with the beach cobble unit. BGS © UKRI 2020.

Photo 4: Image showing the (to our knowledge) previously unreported, recently exposed, well-consolidated sandy mud, found in the foreshore at the western end of Portelet Bay. Clasts are angular to rounded and of mixed lithology. BGS © UKRI 2020.

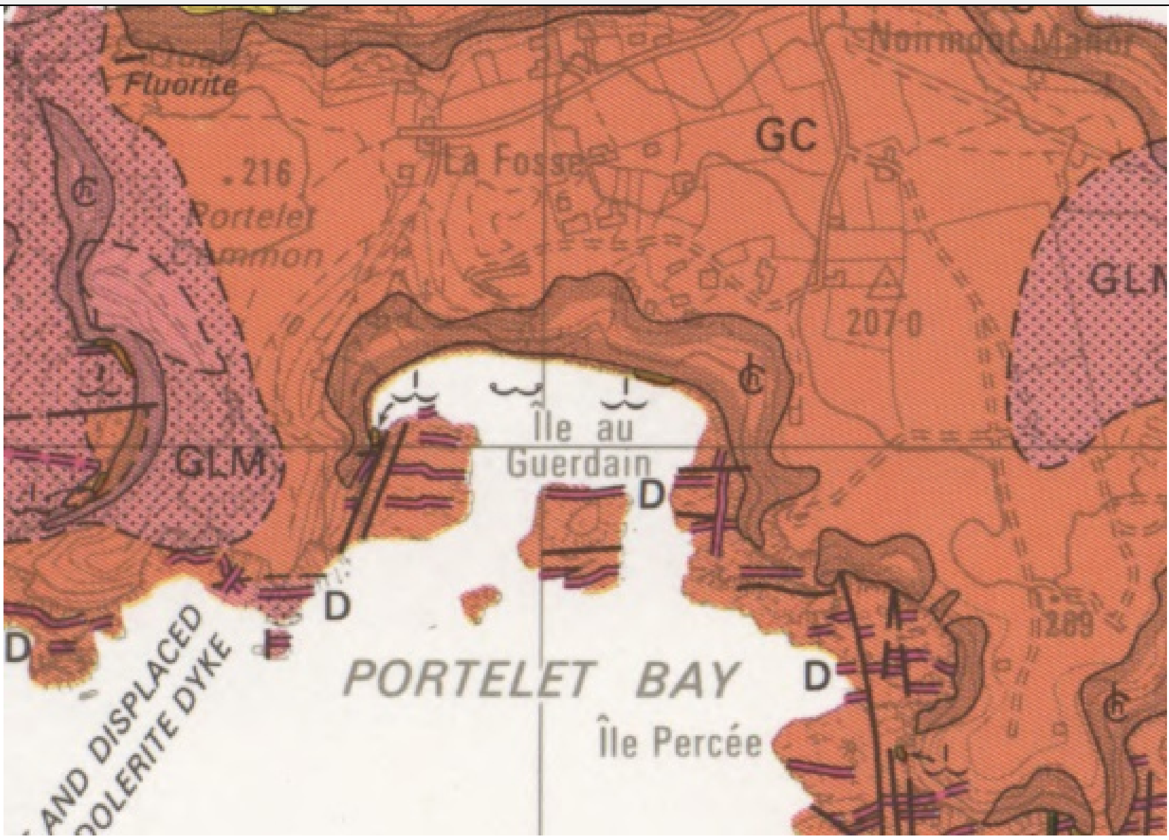
Map of the site boundary on a topographic base

Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph

Imagery ©2020 Government of Jersey.

Published geological map of the site

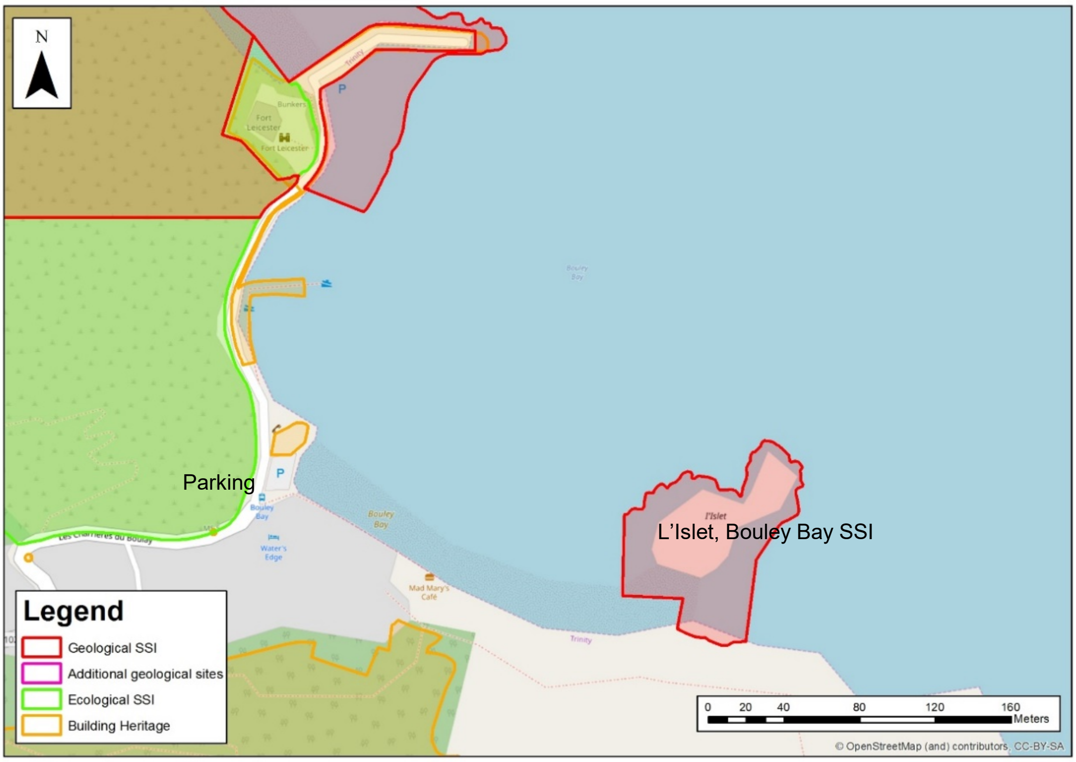


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

7.16 SITE NAME: L'ISLET, BOULEY BAY, SSI

Site Information: The L'Islet, Bouley Bay site comprises a north-facing pebbly sandy bay with a tidal islet on its eastern side and steep-backed coves to the north. L'Islet is cut off at high tide and is a tall pinnacle of vegetated rock with good exposures of head and loess deposits. The bay is popular with tourists and locals, and it has a small harbour; swimming, diving and fishing are all common activities year-round.	
National Grid Reference: Mid-point: 43914, 71496 West end: 43809, 71911 East end: 44154, 71504	**Site Type:** Tidal islet with outcrop exposed in eroded cliffs on the island and exposures in coastal cliffs
Site Ownership: Private	**Current Use:** Coastline, natural, tourism, fishing, recreation
Field Surveyors: J Everest, L Hughes, S Arkley, C Auton, R Kendall and M Gillespie	**Current Geological Designations:** Geological SSI
Date Visited: 22 September 2019 and 13 October 2019	**Other Known Designations:** Built Heritage: Fort Leicester. This area is within Jersey National Park.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Pleistocene	**Formation:** Loess
Rock Types: Silt	
Age: Pleistocene	**Formation:** Head
Rock Types: Bouldery, cobbly	
Age: Late Precambrian (Ediacaran)	**Formation:** Bouley Rhyolite Formation
Rock Types: Predominantly the Lower and Middle Bouley Ignimbrites. The Les Hurets Tuff crops out in the clifftop exposures in the adjacent Les Hurets, Bouley Bay site, and the Upper Bouley Ignimbrite crops out in cliffs and headlands to the south of the site. The main lithologies are ignimbrite, banded rhyolite and tuff.	

Site Description:

Introduction

Bouley Bay is a small, steep-sided, NE-facing bay with a sand and pebble beach. To the north, the beach is bounded by the harbour wall, and the southern end of the beach is marked by the impressive tidal island promontory of L'Islet. The bay is underlain by rocks belonging to the Bouley Rhyolite Formation (*Jersey Volcanic Group*) and is backed by steep slopes comprised of head deposits mantling the bedrock cliffs.

The L'Islet site is an existing SSI formed by an accessible tidal islet at the eastern end of the beach in Bouley Bay. It is an SSI principally because of the exposures of head and loess on the islet, or sea stack, which gives the site its name (Photos 1–3). The bedrock exposed at the site includes ignimbrites, rhyolites and tuffs of the Bouley Rhyolite Formation (*Jersey Volcanic Group*). These rocks show impressive small-scale igneous textures, including welded fabrics (Photo 8) and fiamme (Photo 10) in ignimbrites, flattened pumice shards in tuffs (Photo 9) and flow banding in rhyolites (Photo 11). The igneous textures are best seen on wave-washed blocks rather than on the surfaces of *in situ* exposures, which are largely covered in seaweed, barnacles and algae. The base of L'Islet comprises an outcrop of ignimbrite and banded rhyolite that is capped by frost-shattered, cryoturbated angular gravel (head) and bedded sandy silt (loess). The site exhibits a very clear rock platform, upon which the head and loess deposits have been protected from wave action by the upstanding bedrock outcrop of the locally named Middle Bouley Ignimbrite (Bishop and Bisson, 1989).

Bedrock Units

Bouley Rhyolite Formation (Jersey Volcanic Group)

The bedrock at the L'Islet, Bouley Bay site comprises the locally named Lower and Middle Bouley Ignimbrites of the Bouley Rhyolite Formation. The Les Hurets Tuff crops out in the clifftop exposures in the adjacent Les Hurets, Bouley Bay site, and the Upper Bouley Ignimbrite is exposed in the cliffs and headlands to the south of the site. The Bouley Rhyolite Formation forms part of the *Jersey Volcanic Group* and comprises a sequence of acidic volcanic rocks, including glassy rhyolitic lava flows and ignimbrites, which formed as a result of high-temperature pyroclastic flows and were welded by subsequent compaction. Both the lavas and rheomorphic ignimbrites show flow banding and flow folding as a result of deformation caused by inhomogeneities within the rock during viscous flow. Consequently, in outcrop it is often difficult to distinguish between the lavas and the rheomorphic ignimbrite flows. The originally glassy rhyolites are unstable and started to hydrate and crystallise, or devitrify, soon after they were formed. In contrast to the rocks exposed at the Les Hurets, Bouley Bay site, many of the rocks exposed at the L'Islet site have almost completely devitrified and hydrated. However, the flow banding in the rhyolites and the welding, which resulted in the flattening of lapilli and pumice shards, have not been obscured by spherulite growth.

Comparable with the Bouley Rhyolite Formation exposed at the Giffard Bay, Bonne Nuit and Les Hurets, Bouley Bay sites, the initial interpretation of the volcanic rocks at L'Islet by Mourant (1933c) was that they were dominated by subaerially erupted lava flows (also see Lees and Roach, 1993). However, Thomas (1977) and Bishop and Bisson (1989) later suggested that many of the units within this volcanic formation are in fact pyroclastic breccias (agglomerates) and subaerial pyroclastic deposits, including tuffs and rheomorphic ignimbrite flows. Apart from the study of Thomas (1977), no detailed petrological analysis has been carried out on the Bouley Rhyolite Formation exposed at L'Islet. However, a much wider investigation of the *Jersey Volcanic Group* rocks carried out by Lees and Roach (1993) led them to suggest that 'much of the sequence appears to have accumulated in a subaqueous environment'. In particular, they concluded that the spherulitic rhyolites within the Bouley Rhyolite Formation exposed at the nearby Les Hurets, Bouley Bay site probably formed subaqueously.

No published age dates are currently available for the Bouley Rhyolite Formation rocks at the L' Islet site. Indirect evidence for the age of this volcanic formation is provided by a U-Pb zircon age of 583 ± 3 Ma, which was obtained from a *c.* 130-m-thick flow-banded rhyolite exposed at the Anne Port Bay site (Miller *et al*., 2001). The dated rhyolite flow occurs at or near the top of the volcanic sequence at Anne Port Bay, which is regarded as occurring close to the base of the Bouley Rhyolite Formation. No detailed correlation currently exists between the volcanic sequences exposed at the Anne Port Bay and L' Islet, Bouley Bay sites. However, regional mapping (IGS, 1982) suggests that the ignimbrite-dominated sequence at the L'Islet, Bouley Bay site occurs at a stratigraphically higher level within the Bouley Rhyolite Formation than the dated Anne Port Bay flow, and it is therefore likely to be slightly younger than the published *c.* 583 Ma age.

Quaternary Sediments

L'Islet is a partially vegetated bedrock promontory that is separated from the mainland at high tide, so that it forms a small rocky island some 30 m across; the top of this island sits at *c.* 10 m a.m.s.l. The Quaternary sediments that overlie the volcanic rocks of the Bouley Rhyolite Formation, which form the core of the island, are well exposed on the island's southern landward side. The basal unit of the sedimentary sequence is exposed close to the present-day sea level (Ordnance Datum) and comprises a *c.* 1-m-thick, clast-supported, cryoturbated cobble gravel composed of angular clasts (5–50 cm in length) of banded rhyolite and ignimbrite. Overlying the gravel is 2 m of pale yellowish-brown, weakly stratified loess containing rare, angular cobbles and 10–15-cm-thick beds of angular gravel. The larger clasts within the loess were potentially derived from the head deposits exposed immediately onshore (see Photo 4). It is thought that L'Islet become separated from the mainland around 126–115 ka BP. This is supported by the height of the col that separates the island from the cliff; it is 2 m higher than the present-day sea level (MIS 5e). The 2 m sea level dates to that period (information from J Renouf).

A small exposure of weakly cemented gravel comprising angular rock fragments in an orange-brown silty sand matrix was temporarily exposed (at the time of the site visit) beneath the present pebble beach at Bouley Bay, to the south of the Bouley Bay Dive Centre (Photos 5 and 6). This indurated gravel is thought to be a head deposit containing angular clasts of locally derived volcanic rocks.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Roadside parking by the (disused) Water's Edge Hotel in Bouley Bay
Safety of access	Slippery underfoot, tidal
Safety of exposure(s)	Steep and overhanging in places
Access	Eastwards along the beach across a rocky isthmus to the islet
Current condition	Outcrop actively eroding
Current conflicting activities	Miner bees nesting in sand outcrop
Restricting conditions	Tides, bees
Nature of exposure(s)	Coastal cliff outcrop

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Resistance Nest Bouley Hafen is part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall (HER Number 1200123; Listed building TR0123). The grounds of Rockmount de Moustiers are a fine, extensive, picturesque and sublime landscape around the remains of a unique marine pleasure pavilion, with a variety of Victorian Gothic garden buildings (HER Number 1200094; Listed place TR0013, TR0094, TR0235).
Aesthetic landscape	Scenic location
History of Earth science	No known associations
Economic geology	No known associations

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology	Local	Moderately good	Detailed studies	
Igneous/mineral/meta	Local	Good	Referenced	X
Structural geology				
Palaeontology				
Geomorphology	Local	Good	Referenced	X

Geoscientific Value of the Site

The site is an existing SSI formed by an accessible tidal islet at the eastern end of the beach in Bouley Bay. It is an SSI principally because of the exposures of head and loess on the islet, or sea stack, which gives the site its name. The site also displays ignimbrites, rhyolites and tuffs of the Bouley Rhyolite Formation rocks, which show impressive small-scale igneous textures, including welded fabrics and fiamme in ignimbrites, flattened pumice shards in tuffs and flow banding in rhyolites. However, the igneous textures are best seen on wave-washed blocks of rock rather than on the *in situ* exposures, which are largely covered in seaweed.

Assessment of Site: Current Site Usage	
Community	Dog walking, beach activities, diving, fishing and water sports
Education	Accessible to able children and adults if care is taken

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Trowel excavation should not be undertaken, as the section is small and bees were nesting at the time of the site visit.
Potential use	Education, walks, information board

Site Photos:

Photo 1: View of L'Islet from the west at mid-tide. The modern rock platform is clearly marked by the blackened rhyolitic (Middle Bouley Ignimbrite) bedrock. The loess deposit, visible on the right-hand side of L' Islet in this image, has been protected by an upstanding promontory of rhyolite at the northern end of the feature. It is assumed that L'Islet was formerly connected to the main coastal slope to the south (right-hand side of image) by a continuation of the loess and head deposit, which was removed by wraparound wave action during the Holocene. BGS © UKRI 2020.

Photo 2: Section through loess deposits, exposed on the southern side of L'Islet. BGS © UKRI 2020.

Photo 3: Close-up of the loess deposits on L'Islet, showing 2 m of pale yellowish-brown, slightly stratified loess with rare angular clasts and 10–15 cm beds of angular gravel and cobbles. BGS © UKRI 2020.

Photo 4: Head deposits exposed at the back of Bouley Bay, immediately south of L'Islet. During cold climate conditions, repeated freezing and thawing causes the frost shattering, erosion and disaggregation of exposed bedrock surfaces. This broken material moves downslope and accumulates at the bases of slopes. As shown here, the thickness of these deposits can be considerable around Jersey's coasts. BGS © UKRI 2020.

Photo 5: Weakly cemented gravel with angular clasts in a silty sand matrix. This is possibly a head deposit exposed beneath the present pebble beach at Bouley Bay; it is located to the south of the Bouley Bay Dive Centre (in the background). BGS © UKRI 2020.

Photo 6: Close-up of the indurated and weakly cemented possible head deposits exposed on the beach at Bouley Bay. Note the angular clasts of volcanic rocks, which contrast with the more rounded cobbles of the modern beach (shown in Photo 5). BGS © UKRI 2020.

Photo 7: Viewing platform at Bouley Bay. An interpretation board describing the geology/geomorphology of the bay could be placed here next to the existing historical board. BGS © UKRI 2020.

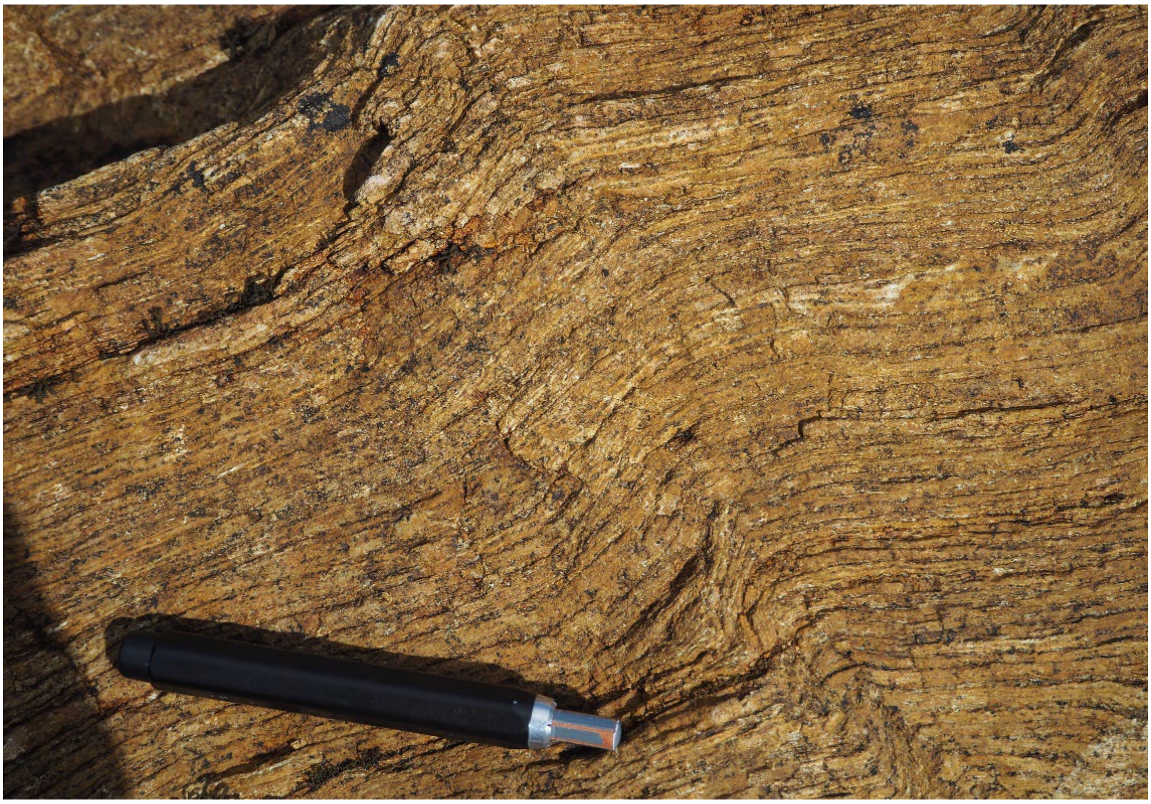


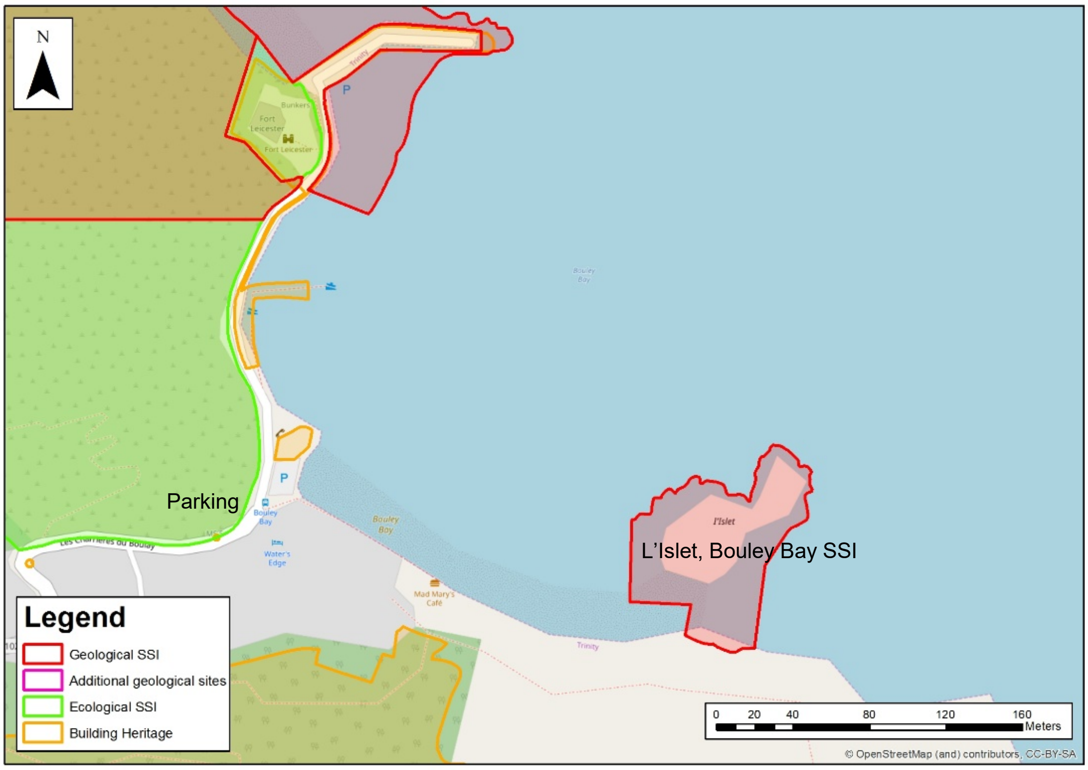
Photo 8: Close-up of a loose block in Bouley Bay, close to L'Islet, displaying welded layering in the Middle Bouley Ignimbrite. BGS © UKRI 2020.

Photo 9: Close-up of a loose block in Bouley Bay, close to L'Islet, displaying flatted pumice shards within a tuffaceous portion of the Bouley Rhyolite Formation. BGS © UKRI 2020.

Photo 10: Close-up of probable flow banding within a loose block of the Bouley Rhyolite Formation in Bouley Bay, close to L'Islet. BGS © UKRI 2020.

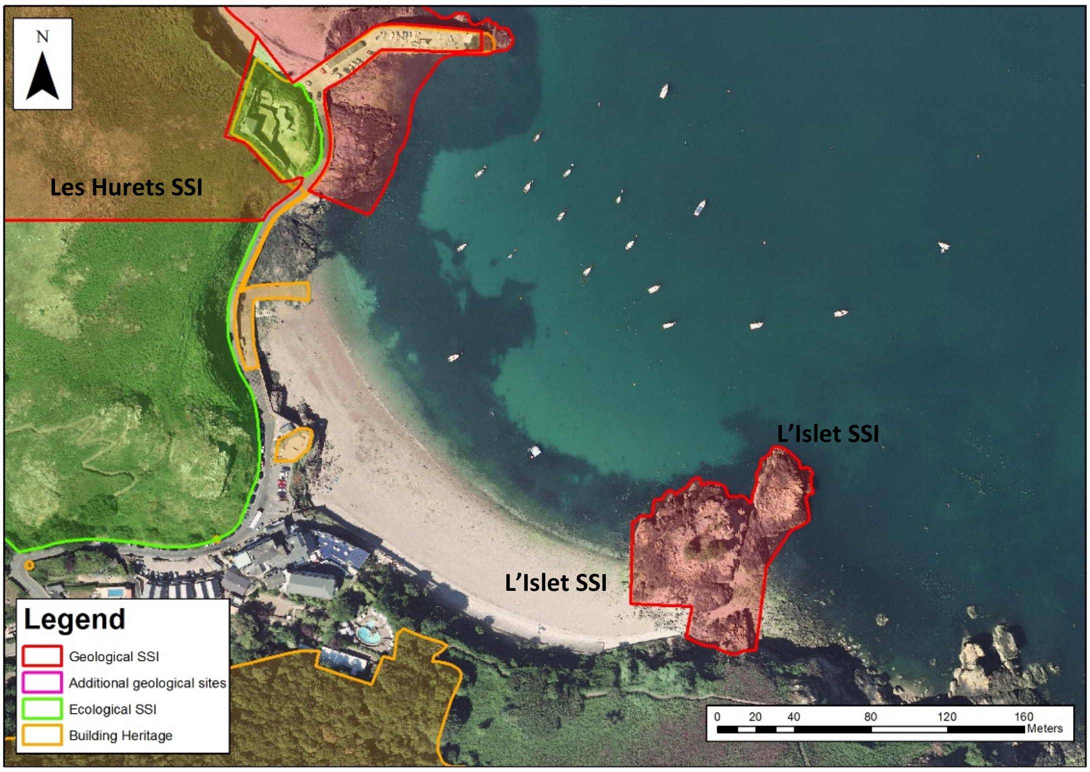
Photo 11: Middle Bouley Ignimbrite showing well-developed parataxitic texture. Fiamme (flattened and streaked out pumice fragments) are very pale pink in colour and may reach 0.5 m in length. GM Thomas, 1976. BGS © UKRI 2020.

Map of the site boundary on a topographic base



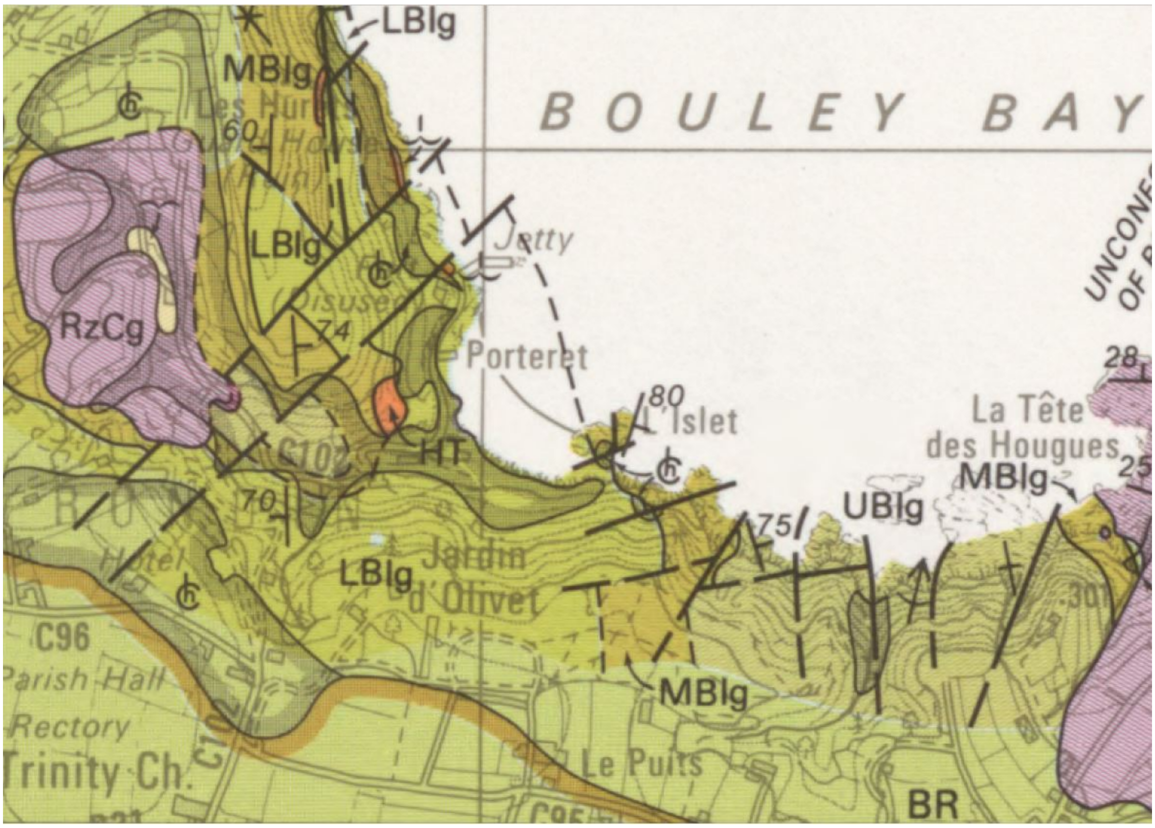
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

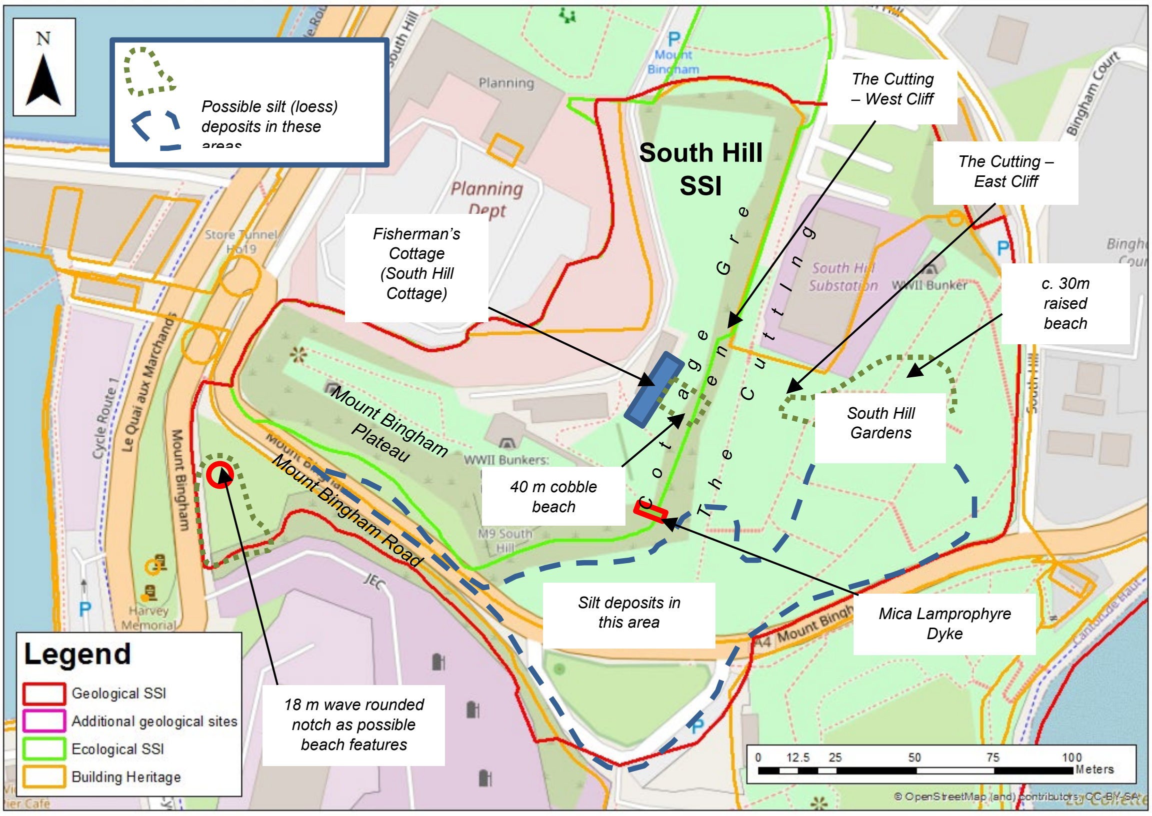
7.17 SITE NAME: SOUTH HILL, SSI

Site Information:

The geology and geomorphology exposed at the South Hill SSI comprise (1) a raised beach complex composed of a cobble beach at 40 m on the South Hill plateau, a finer-grained marine beach at *c.* 30 m in South Hill Gardens, a range of cold stage loessic deposits bordering the Mount Bingham road below South Hill and a wave-rounded outcrop of granophyre to the south-west of the road on the corner; and (2) a lamprophyre dyke cutting the Fort Regent Granophyre. The cobble beach occupies a high-tide gully some 6 m wide x 3 m deep that is visible behind protective geotextile fabric at the rear of the Fisherman's Cottage; an earlier cross-section through the deposit at the top of the cutting is now concealed beneath vegetation, as is most of the lamprophyre dyke. The 40 m cobble beach is the only known cobble beach at this height in the Channel Islands and the adjacent Cotentin; no other examples currently exist in this area.

National Grid Reference: Mid-point: 41953, 64633 West end: 41806, 64509 East end: 41806, 64509	**Site Type:** Natural landform
Site Ownership: Public	**Current Use:** Recreation, public park (South Hill Gardens)
Field Surveyors: J Renouf, S Arkley and C Auton	**Current Geological Designations:** Geological SSI
Date Visited: 16 October 2019 as part of this audit; visited on other, previous dates by J Renouf	**Other Designations:** Ecological SSI: Fort Regent, Building Heritage: Fort Regent and South Hill Battery (HE1195) and South Hill Park (HE1898)

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Quaternary	**Formation:** 40 m raised beach
Rock Types: Clast-supported, well-rounded cobble gravel	
Age: Quaternary	**Formation:** 30 m raised beach deposits
Rock Types: Sandy to silty deposits with pebbles and basal head	
Age: Quaternary	**Formation:** 18 m wave-cut notch and platform
Rock Types: Wave-rounded notch and associated wave-smoothed platform	
Age: Late Precambrian (Ediacaran)	**Formation:** *South-east igneous complex*
Rock Types: Fort Regent Granophyre	
Age: Late Precambrian (Ediacaran)	**Formation:** Sills and dykes
Rock Types: Dolerite sill/dyke	

Site Description:

Introduction

The geology and geomorphology exposed at the South Hill SSI comprises (1) a raised beach complex composed of a cobble beach at 40 m on the South Hill plateau, a finer-grained marine beach at *c.* 30 m in South Hill Gardens, a range of cold stage loessic deposits bordering the Mount Bingham road below South Hill and a wave-rounded outcrop of granophyre to the south-west of the road on the corner; and (2) a lamprophyre dyke cutting the Fort Regent Granophyre. The cobble beach occupies a high-tide gully some 6 m wide x 3 m deep that is visible behind protective geotextile fabric at the rear of the Fisherman's Cottage; an earlier cross-section through the deposit at the top of the cutting is now concealed beneath vegetation, as is most of the lamprophyre dyke. The 40 m cobble beach is the only known cobble beach at this height in the Channel Islands and the adjacent Cotentin; no other examples currently exist in this area.

Bedrock Units

South-east igneous complex

The Fort Regent Granophyre (a component of the *South-east igneous complex*) forms the dominant bedrock at South Hill. It is well exposed in steep road cuttings around Fort Regent and in former quarry faces around South Hill (Photos 1 and 2) The granophyre is a medium-grained granitic rock with a subhedral to anhedral texture. It is composed of tabular plagioclase, which is partially altered to sericite and mantled by K-feldspar, and quartz (Photo 3). The rock is well jointed and is pinkish-orange on weathered surfaces. It is intruded by lamprophyric and basic doleritic dykes. The Fort Regent Granophyre is comparable to the granophyre that crops out at Elizabeth Castle; these granophyres are Late Precambrian (Cadomian) in age and part of the younger portion of the *South-east igneous complex* in Jersey. The geological map shows that both doleritic and lamprophyric dykes are intruded into the granophyre at South Hill. The dyke that crops out at the base of the southern end of the Cutting on its overgrown east face (Photo 4) was described as a 'minette' (biotite lamprophyre) by Bishop *et al.* (2003). However, it is lighter in colour than the biotite lamprophyres and was described as a leucocratic hornblende–mica lamprophyre by Bishop *et al.* (1989), a view corroborated by field examination during this study. This means that this dyke is a spessartite rather than a minette. The lamprophyre dyke is up to 3 m thick, but, at present, the contacts against the granodiorite are concealed by vegetation. The abundance of mica in the rock is evident from the silvery appearance of the weathered surface of the dyke, and spheroidal ('onion-skin') weathering is well developed on the current exposure (Photo 4). Earlier descriptions indicate that the lamprophyre is cut by a later, thinner basic dyke and that the lamprophyre is also displaced by small-scale, high-angle faulting. The archive photograph (Photo 5) confirms the displacement of the lamprophyre by small-scale faulting; the presence, or absence, of a later cross-cutting dolerite dyke is less evident. The archive photograph does suggest, however, that the contacts between the lamprophyre and the granodiorite host rock are sharp and planar, and there is little change in the thickness of the dyke across the exposure.

Quaternary Sediments

The 40 m raised beach deposit on the Cottage Green (see the site map)

The highest and oldest known Quaternary unlithified marine beach deposit in Jersey is at a maximum height of 42 m and occurs at South Hill, St Helier (Dunlop, 1893; Dunlop, 1911; Dunlop, 1915; Naish, 1919 [the best description]; Mourant, 1933b; Mourant, 1935; Zeuner, 1945; Keen, 1978, 1993; Bishop *et al.*, 2003; Renouf and James, 2010). Whether this beach was once linked across the Cutting to that at 30 m at the top of South Hill Gardens to the east is not known, although this may be the case; here, it is treated separately under its 30 m height. The 40 m beach can be seen behind the Fisherman's Cottage near the top of the road leading to the top of the Mount Bingham Plateau (Photo 6). The deposit occupies a wave-smoothed gully cut into the top of weathered granophyre and consists of a deeply altered cobble gravel, which is composed of granophyre but with variable amounts of uniform fine silt adhering to the cobbles. The gully measures *c*. 6–7 m long x 3 m deep. The exposure is unfortunately covered by geotextile fabric. The beach continues beneath the lawn to the east, where it used to be visible (Photo 7) in a shallow gully cut into the rock at the top of the west cliff of the Cutting. It is now hidden beneath thick vegetation, but the base of this exposure of the beach in the cliff is known to be at *c*. 37 m. Further south along this cliff, at the top of the lamprophyre dyke at a height of *c.* 45 m, is a further channel with some residual gravel and angular granophyre and dyke fragments sitting on the eroded-out dyke (Photos 5 and 8). To the west of the cluster of buildings and beyond the fortifications on the plateau top there is an open area – the Mount Bingham Plateau – with fine views in many directions (Photo 9). Within this space there is a low-lying outcrop of partially vegetated granophyre, which appears to be a possible relict wave-smoothed rock platform. It occurs at the right height to belong to a mid- to upper-level intertidal zone of the 40 m beach.

The 30 m raised beach to the east of the Cutting

The 31–35 m raised beach on the opposite (east) side of the Cutting, both along the top of the cliff and at the top of South Hill Gardens, is poorly exposed. The description by Mourant (1933) states that 'it consists of small pebbles and sand and is quite different in appearance from that at the higher level; it looks younger . . . the rock underlying this eastern exposure is disturbed so as to almost resemble head. That the disturbance was produced before the beach was laid down is shown by the state of some large blocks of granite, which are well rounded above where they are in contact with the beach, but angular below. The beach is also overlain by a thin deposit containing angular blocks' (Photo 10).

The 18 m wave-smoothed notch and associated platform

This feature projects out of a grassy area to the south of Mount Bingham Road at the first corner following the hairpin bend. It is likely that a much larger area of the associated wave-smoothed platform would be revealed if the grass cover were removed. Across the road to the east is a triangular, roughly grassed area between the road and the cliff; it links into the range of deposits at the southern end of the Cutting (see Le Quesne [2021] for evidence of these silt-rich sediments of likely loessic origin displayed in a series of trial pits). Whether these silt-rich deposits of certain cold stage origin directly followed the interglacial OIS 7 or are of Devensian/Weichselian age and formed following the high OIS 5e sea level, the shelf on which they have accumulated must be regarded as a possible site for human occupation given the known occurrence of Neanderthals in the cave of La Cotte à la Chèvre, for instance, at this height.

A range of shelf features around the cliffs of the island occur more or less at the 40 m level and are linked by Renouf and James (2010) to this particular high sea level.

The only other deposit assigned to the 30 m raised beach is that of Bouilly Port (Nichols and Renouf: jerseygeologytrail/superficial deposits/raised beaches); it is a roadside shallow gully containing rounded cobbles passing downward into thin gravelly head resting on the granite bedrock. However, there are a number of examples of shelf features around the cliffs of the island that probably correspond to this high sea-level event (Renouf and James, 2010).

Apparently absent from South Hill is any identifiable evidence of the St Clement raised beach at *c*. 25 m (Renouf and James, 2010). Evidence, if it exists, could be hidden under the zone extending from the 18 m notch on Mount Bingham up to the entry to the Cutting, where the loessic deposits have been found, or on the eastern slopes of South Hill Gardens.

The 18 m sea level responsible for the wave notching adjacent to the Mount Bingham Road belongs to a series of island localities where raised beaches, wave-cut notches, caves and coastal cliff shelves have been identified. Three important examples are Le Pinacle, La Cotte à la Chèvre and the upper level of Belle Hougue I.

Dating of the raised beach sequences

There has been a long history of attempts to date the great variety of seashore features occurring throughout Armorica, northern France and along the southern parts of Britain. Though it was often proposed as very likely, the notion that the evidence for the different sea levels reflected a succession from oldest (for the highest sea level) to youngest (for the lowest sea level) was criticised just as often. In recent decades, with greater precision on a variety of scientific fronts, the general linkage between height and age has been largely supported. Work by Coutard in the northern Cotentin (2003 and later publications) and the work of Renouf and James (2010) in the Normanno-Breton Gulf, including the Channel Islands, have linked the raised sea-level features to the well-accepted 100 ka climatic cycles:

- 40 m – OIS 13 (*c*. 490 ka)
- 30 m – OIS 11 (*c*. 390 ka)
- 25 m – OIS 9 (*c*. 300 ka)
- 18 m – OIS 7 (*c*. 200 ka)
- 8 m – OIS 5 (126–115 ka)

(Renouf and James, 2010; Coutard, 2003)

The value of this advance is that it allows estimates to be made of where it might be useful to look for evidence of Neanderthal habitation outside of the known sites of La Cotte de St Brelade and La Cotte à la Chèvre or for more recent *Homo sapiens* localities, such as Les Varines. Refinements of the above dating are ongoing.

Interpretation of the 40 m raised beach at the South Hill site

There are a variety of features related to past sea levels and other elements found at South Hill. Taken together, they have contributed to the creation of a complex geomorphology likely spanning a 500 ka time span, if the OIS 5e shoreline features now buried beneath land reclamation are included. This period also coincides with one of the unprecedented development stages of hominins, in particular, the full transition from *Homo heidelbergensis* to Neanderthals and on a separate line to us – *Homo sapiens*. Jersey is richly endowed with the Neanderthal story, developed from the thick and varied deposits of La Cotte de St Brelade and the nearby finds at Le Rozel on the Cotentin shores opposite the island. In recent years, the Magdalenian modern human presence at Les Varines has contributed another exceptional part of the hominin story.

Throughout the hundred-thousand-year cycles of the last 500 ka, an ever-present tension within Jersey and the other Channel Islands and around the Normanno-Breton Gulf in general has been related to the consequences of sea-level changes. The changes are not just related to the evidence of past sea levels *per se*; they have been reflected in the climatic, vegetational and other changes that occurred as sea levels rose and fell. The farther back in time one goes, the patchier the evidence of the environmental situation at different times is, and this is where the value of the South Hill site becomes apparent. It provides an opportunity to identify potential landscapes of the 500 ka OIS and track their evolution through the next 300 ka to the time of the 18 m high sea level, *c*. 200 ka.

There is enough surviving evidence on and around South Hill to enable a geological interpretation that envisages a sea level whose highest tidal deposit is a cobble beach at some 40 m. It is possible that the lowest tidal levels of this beach are preserved at the top of South Hill Gardens, although these are at a height at the extreme limit of a likely maximum tidal range of 12 m, if this range is directly comparable with that of the present. It is also possible that this second beach reflects a retreat stage of the 40 m maximum (cf. Coutard, 2003, p. 366, figure V.4). However, if this beach belongs to the 30 m group (Renouf and James, 2010), then it provides evidence for the continued existence of shorelines around South Hill and a measure of the continuing relief of the geomorphological entity. Unfortunately, the evidence from other deposits in South Hill Gardens and at the southern end of the Cutting is confusing; the first description of the site by Dunlop (1893) is difficult to interpret. However, the recent evaluation of the area at the mouth of the Cutting by Le Quesne (2021), who recorded the results of a series of trial pits, provides evidence that some of the deposits represent cold stage loessic silts. Such silts are likely to extend downhill towards the 18 m notch on the hill corner below. Of particular importance is the possibility this offers of using the thermo-luminescence (TL) method to date the deposits. The possibilities are likely to be either pre-OIS 7 (*c*. 200 ka), if they represent the cold stage preceding the high 18 m sea level, or post-OIS 7, if they are loessic deposits from the younger cold stages of the Wolstonian/Saalian or even the Devensian/Weichselian. Overall, the geomorphological succession of events that led to the present dramatic relief of South Hill represents a glimpse deep into Jersey's more recent geological past, which has implications for understanding the Palaeolithic landscapes of the Normanno-Breton Gulf and the gulf's coastal development during the past 500 ka of hominid evolution, building on what is already known.

The extent of this evolution, particularly the magnitude of the change in the relative sea level, can be appreciated by Earth scientists and the general public alike if they simply view nearby St Helier Harbour and the extensive shore platforms of the south-east from the southern highpoint of the Fort Regent promontory at South Hill, which is capped by an ancient beach.

Assessment of Site: Access and Safety

Aspect	**Description**
Road access and parking	A number of public parking areas are available within easy walking distance of South Hill; the closest lies to the south of the site, off the A4 Mount Bingham Road.
Access to the site	There is open access into and around South Hill. The quarried faces of the Cutting are either well vegetated or difficult to access. The 40 m raised beach itself is at the rear of a privately occupied cottage and thus special permission is required to inspect it.
Safety of access	The Mount Bingham Plateau is readily accessible up a tarmac road past several buildings. South Hill Gardens, to the east of the Cutting, mainly consists of areas of cut grass and woodlands; there are footpaths through the park, making access safe and easy.

Safety of exposure(s)	The former quarry faces are approximately 20 m high; visitors are advised to wear hard hats if they wish to inspect the rocks up close, as areas of the exposed faces appear to be broken and loose. This is particularly true for the south face, where a ‘rock fall’ warning sign is in place. The west face of the Cutting is likely to be more stable due to its dense vegetation cover, but care should still be taken.
Current condition	The south face is partly obscured by vegetation, and the east face is almost completely obscured by vegetation, which is mainly ivy on the face and shrubs/brambles at the base.
Current conflicting activities	None known
Restricting conditions	Vegetation and private land obscure large portions of the west face of the Cutting, to the extent that the 40 m raised beach deposits are not currently visible or accessible at this locality.
Nature of exposure(s)	Varied, in part a former quarry face

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	South Park Hill comprises informal, clifftop, 20th-century grassy areas and seaside gardens incorporating historic military features (HER Number 0401898; Listed place HE1898). Fort Regent, located immediately north of the geological SSI on the hill above St Helier (Mont de la Ville), was built between 1806 and 1814. The fort also includes South Hill Battery, developed starting in the late 18th century, and 18th-century Signal Station, which has been operational since 1792 and is one of the oldest signal stations in the British Isles (HER Number 0401195; Listed building HE1195, HE1917). The fort was constructed following the Battle of Jersey in 1781, which showed the Island's need for a more modern and better-placed fortress than Elizabeth Castle. Lithics have been discovered nearby in the La Collette area (HER Number 0400825). Opposite South Hill are La Collette Gardens, which are formal 20th-century seaside gardens (HER Number 0401896; Listed place HE1896), and La Collette Barracks, which are rare surviving late-18th-century engineers' barracks (HER Number 0401219; Listed building HE1219). It is the site of an Allied Prisoner of War Camp, which was erected during World War II (HER Number 0401557; Listed building HE1557). The Military Barracks Office was built in the early 19th century and was used as a late-19th-century military prison and as a prisoner-of-war camp during World War II (HER Number 0401561; Listed building HE1561). Also nearby is the Fisherman's Cottage, an early form of a single-storey building, which is now a rare type in Jersey (HER Number 0401218; Listed building HE1218). South Hill Gymnasium is an unusual example of a 19th-century military gymnasium associated with Fort Regent (HER Number 0401839; Listed building HE1839).
Aesthetic landscape	Impressive views to the south and south-east and across the harbour from Mount Bingham Plateau, South Hill Gardens and Fort Regent
History of Earth science	Visited in 1896 as part of a British Association for the Advancement of Science meeting that was held in Jersey
Economic geology	South Hill Quarry (the Cutting) was, for many years, the scene of work by the War Department, who took stone from the Cutting to build many of the forts that can be seen around the Island today. In later years, civilian contractors took over the extraction of the stone, and much of it was used as rubble filling for harbour extensions and the making of concrete blocks. After the end of the 19th century, the quarry was deserted until the 1920s, when the unemployed were hired to fill it in.

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology	International	Excellent		X

Geoscientific Value of the Site

South Hill is the southern part of the Mont de la Ville (or Town Hill) and was a steep-sided eminence separated from the Glacis of Fort Regent by a low col. As a result of its incorporation into the overall fortified complex of the Mont de la Ville (Fort Regent plus South Hill), it ended up with a combination of largely natural cliffs (the southern cliff and that of the west-facing enclave, which was occupied by the Planning Office and ancillary buildings) and scarped faces – often subject to later quarrying – which produced the Cutting and the adjacent cliffs. In spite of all the military works and subsequent quarrying that took place between the close of the 18th century and the period before and after fort construction (1806–1814), remnants of natural geological features have survived. Most notable is the 40 m cobble beach found occupying a gully some 6–8 m wide by 3 m deep extending across the Cottage Green lawn area between the western face of the Cutting and the Fisherman's Cottage. This raised beach is the highest and oldest known sedimentary deposit within the Normanno-Breton Gulf. (A raised beach of similar height to the east of Cherbourg [Maupertus-Le Castel; Coutard, 2003] no longer exists.)

Views from the site to the present-day coast give a compelling illustration of the amount of sea-level rise, resulting from tectonic movement, that has occurred in Jersey over the last half million years. Because of its significance in understanding the history of Quaternary sea-level change in Jersey and its relationship with other sites in the Normanno-Breton Gulf and further afield in northern France and southern England, it is considered that this site is of international importance, and efforts should made to clear the vegetation covering parts of the cliff, because it currently obscures the raised beach gravel from view.

Assessment of Site: Current Site Usage	
Community	South Hill and South Hill Gardens are maintained green spaces within St Helier that are frequented by locals and visitors.
Education	The overgrown condition of the quarry faces significantly reduces the detailed educational value of the site. However, the site is invaluable on a larger scale in illustrating, to anyone, the heights reached by former sea levels in Jersey and the coastal areas that would have been submerged.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	It is unclear whether the thick vegetation cover on the quarry faces is detrimental (penetrating roots could break up the deposit) or beneficial (provides protection) to the quarry face exposures.
Potential use	The site could be used to promote how Jersey records former sea-levels.

Photo 1: The scarped southern quarry face of South Hill above Mount Bingham Road composed of Fort Regent Granophyre. The face is c. 15 m in height and the lower parts of the exposure are covered in vegetation. The granophyre is very similar to the Elizabeth Castle Granophyre, both are Cadomian (Late Precambrian) age and part of the younger portion of the Jersey *South-east igneous complex*. BGS © UKRI 2020.

Photo 2: Exposure of leucocratic hornblende-mica lamprophyre dyke at the base of the overgrown southern extremity of the west face if the South Hill Cutting. BGS © UKRI 2020.

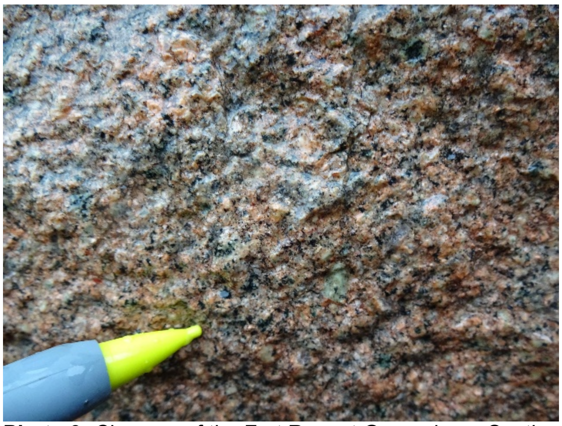


Photo 3: Close up of the Fort Regent Granophyre, South Hill. The granophyre is a medium-grained granitic rock composed of tabular plagioclase, partially altered to sericite and mantled by K-feldspar, and quartz. Graphic intergrowth of the K-feldspar and the quartz are visible under the microscope. BGS © UKRI 2020.

Photo 4: Spheroidal weathering of the leucocratic hornblende –mica lamprophyre dyke seen in photos 1 and 2. The dyke is up to 3 m thick and cuts the Fort Regent Granophyre, but the contacts are concealed by vegetation. BGS © UKRI 2020.

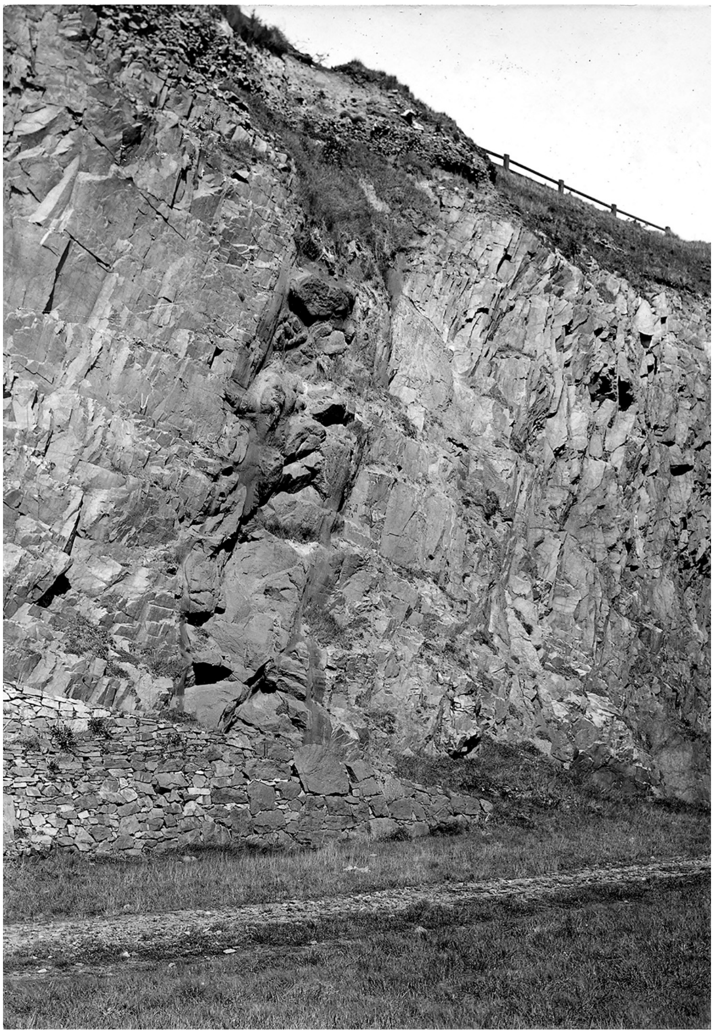


Photo 5: Archive photography of the southwest corner of the west face of the Cutting on South Hill, taken by S.H. Reynolds, during the 1896 British Association for the Advancement of Science field meeting in Jersey. The image shows the lamprophyre dyke intruded into the Fort Regent Granophyre with evidence of the jointing normal to the intrusion's sides which was exploited by weathering to create the corestones just to be made out in Photo 1. At the top of the cliff, the dyke and immediately adjacent granophyre has been weathered and altered by likely gelifraction processes during the last Cold Stage. BGS Imagebase image P234903. BGS © UKRI 2020.

Photo 6: The South Hill raised beach is presently exposed in a 6x 3 m cross section behind the Fisherman's Cottage. Unfortunately the whole section is covered in geotextile and is also on private land. Photo by John Renouf, 2015.

Photo 7: This photograph was taken by BGS photographer CJ Jeffery in 1976 during the geological survey of Jersey. The following description of the sediments was written by DH Keen: 'South Hill, St Helier, Jersey: The deposits consist of rounded and sub-rounded pebbles and cobbles of granite resting on a worn surface of granite. The beach becomes sandier upwards and is capped by angular debris, perhaps of periglacial origin.' BGS Imagebase Image P005422. BGS © UKRI 2020.

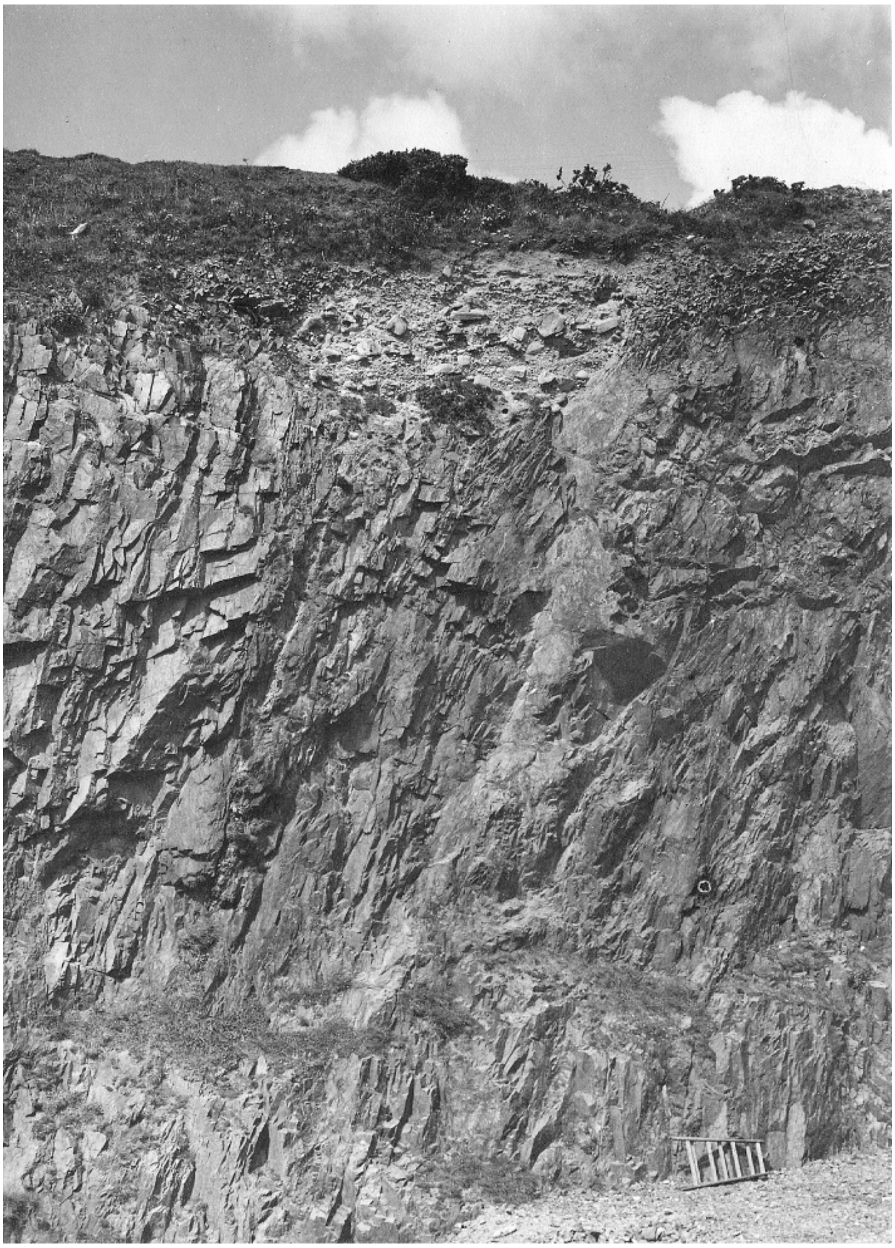


Photo 8: This photograph was included in the Geological Section Report (1915 Bulletin of the Société Jersiaise, 8, 1 :49–52, Plate IV) by Andrew Dunlop. It is the best photograph there is of the gully containing the 40 m raised beach, taken before vegetation obscured it. The section ranges in height from 37 to 42 m. Credit: SJPA/015026.

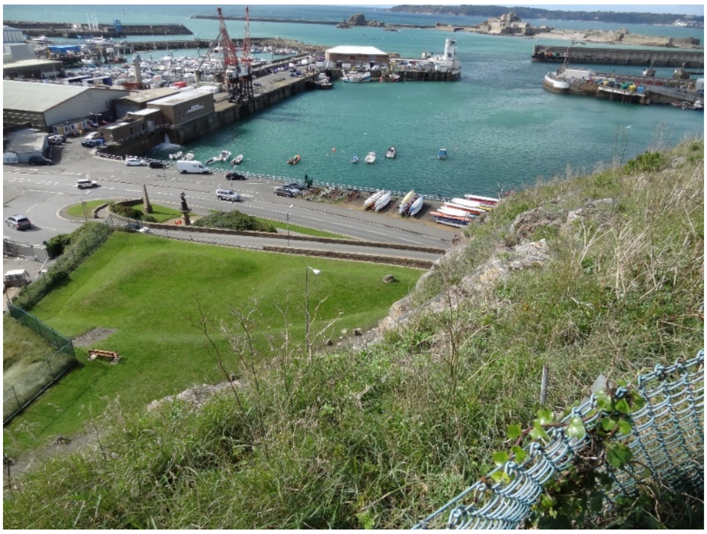
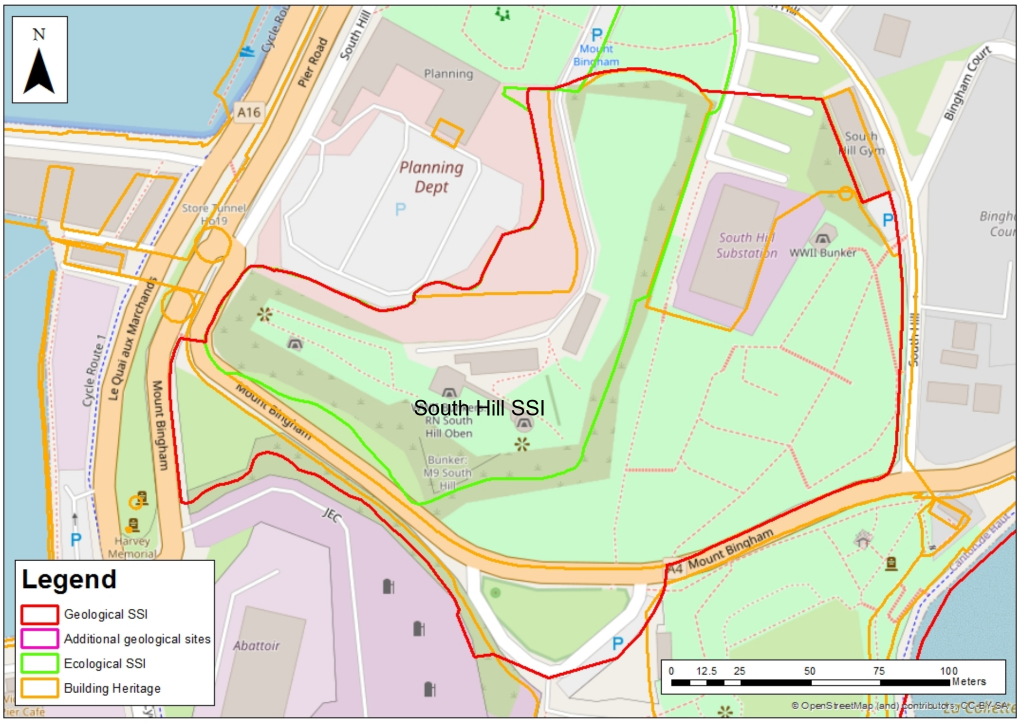


Photo 9: The rounded granophyre outcrop on the right of the green is the 18 m raised beach wave-smoothed rock outcrop. The view beyond shows part of the harbour area with Elizabeth Castle beyond and the Noirmont Martello tower in the far distance. Photo by J Renouf, 2015.

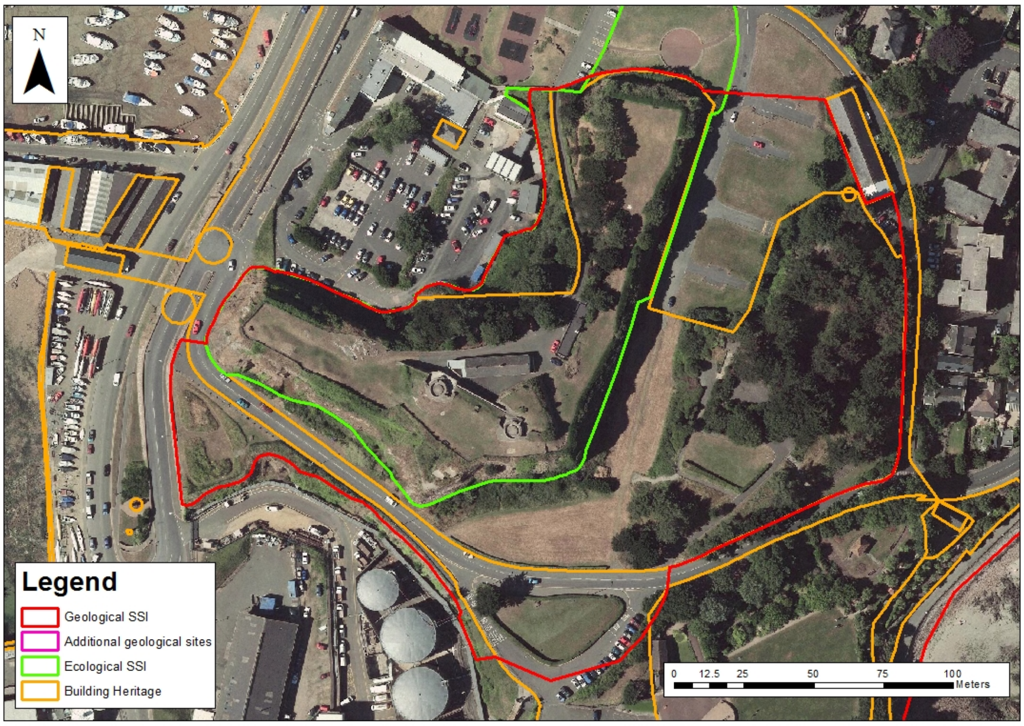
Photo 10: This photograph was provided by R Nichols; it is a close-up of well-rounded cobbles of granodiorite in the exposure of the South Hill 30 m raised beach from the garden of a private house close to the original South Hill Gardens site. The cobbles occur within variable matrices, which include pure silts and areas of coarse sand and angular fine gravel, as shown here. Photo by R Nichols (PhD Wales), Sec. Geology Section, Société Jersiaise.

Map of the site boundary on a topographic base



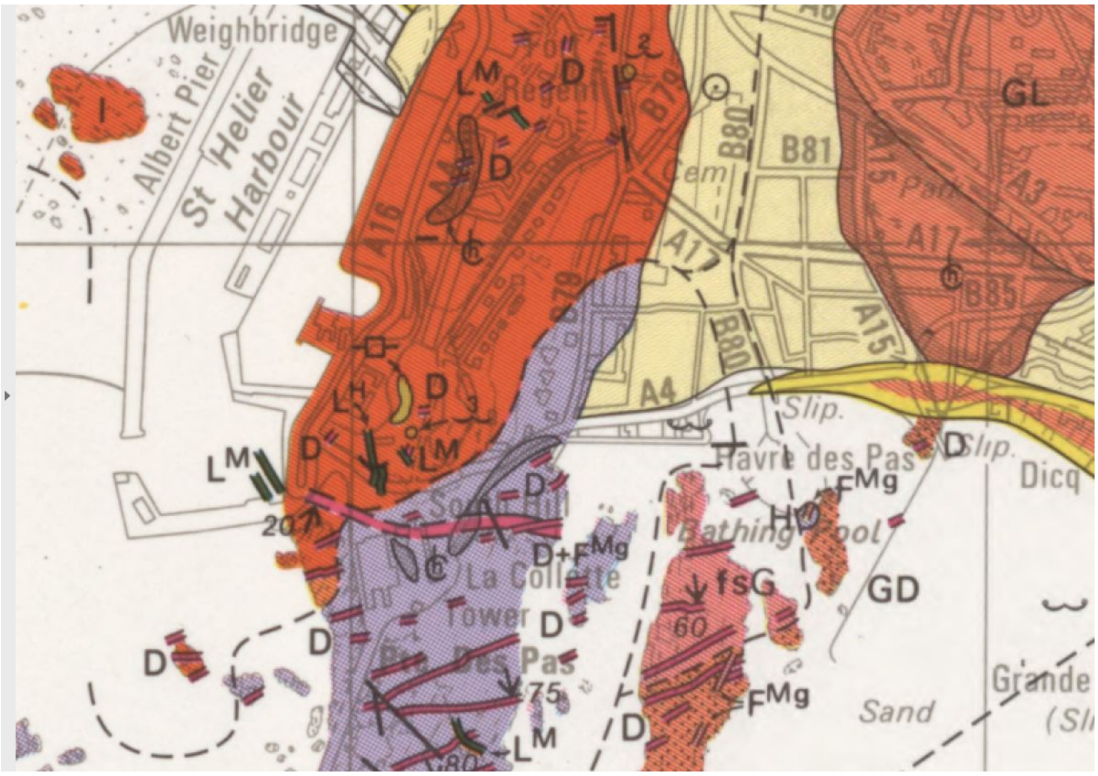
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

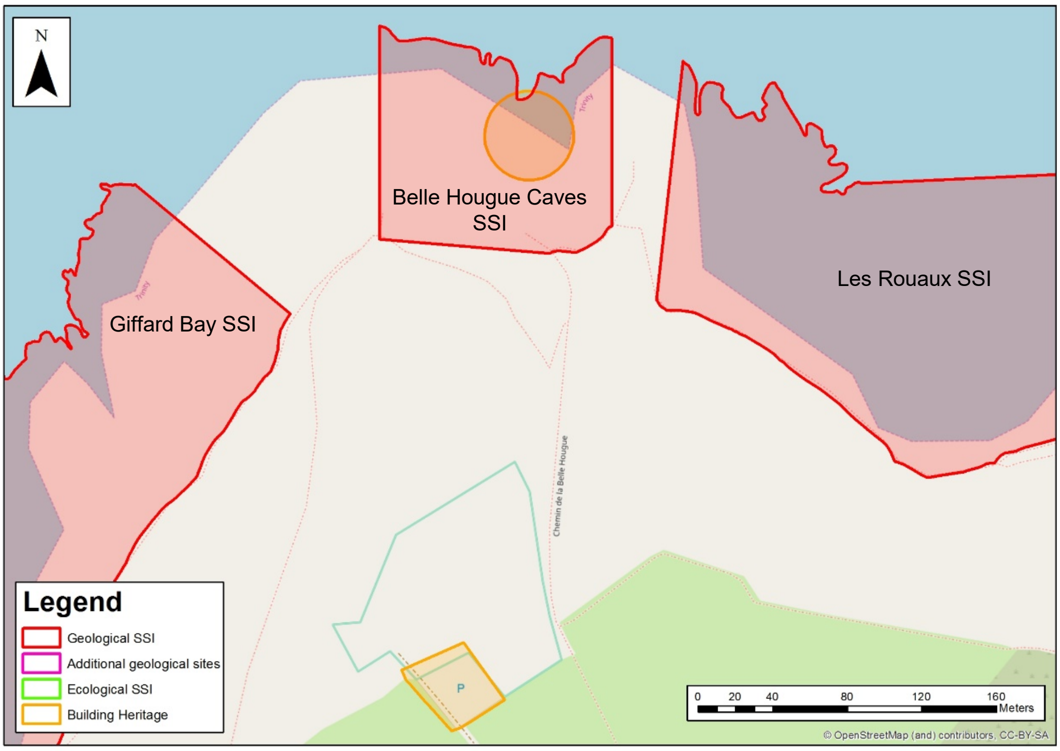


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

7.18 SITE NAME: BELLE HOUGUE CAVES I AND II

Site Information:	
Belle Hougue Caves I and II is an existing SSI on Jersey's north coast. It comprises two sea caves eroded into the faulted dioritic rocks of the headlands; they feature two raised wave notches at 18 and 8 m. The 8 m notch includes a beach deposit dated to the last interglacial. Archaeological finds within the Quaternary deposits inside the cave are unique at this height above sea level within the Channel Islands and include marine molluscs along with bones and antlers from a now-extinct dwarfed red deer. While no confirmed human artefacts have been found, the possibility that the caves were used by people during the Palaeolithic remains.	
National Grid Reference: Mid-point: 42544, 73326 West end: 42485, 73326 East end: 42609, 73326	**Site Type:** Natural feature (coastal cave)
Site Ownership: Part public and part private	**Current Use:** Open country, coastal
Field Surveyors: S Arkley and C Auton. Prehistoric notes from M Pope and M Bates	**Current Geological Designations:** Geological SSI
Date Visited: 17 October 2019	**Other Designations:** Within Jersey National Park

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Site Description:

<u>Introduction</u>

Belle Hougue Caves I and II is an existing SSI. It was designated an SSI due to its international importance as a rare example of a coastal locality that preserves Pleistocene-aged gravels with animal and shell remains. The deposits have been dated by both U-series and amino acid methods to ±121 ka BP, i.e., MIS 5e of the Ipswichian Interglacial. These deposits are thought to have been deposited during the high sea level associated with the Ipswichian warm stage. The site is also important because it is the type locality for *Cervus elaphus jerseyensis ZEUNER,* a species of dwarfed red deer.

<u>Bedrock Units</u>

Belle Hougue igneous complex

Belle Hougue Caves I and II occur within dark-coloured basic and intermediate igneous rocks of the Belle Hougue igneous complex, which is thought to be related to the *North-west igneous complex* but is separated from it by faulting (Bishop and Bisson, 1989). The Belle Hougue complex rocks extend eastwards from Belle Hougue Point onto the adjacent Les Rouaux site; at both localities, they are, in general, separated from rocks of the Jersey Shale (preserved as a pendant of country rock) and St Saviour's Andesite formations by Les Rouaux Fault.

The rocks of the Belle Hougue igneous complex are described by Bishop and Bisson (1989) as 'consisting mainly of altered diorite, veined and brecciated by granite' (Photo 3). They were mapped by Mourant (1933) as syenite and gabbro, 'mixed with other rocks'; syenite and pink granite are recorded within the altered diorites in the exposures at the Les Rouaux site.

Coarse-grained, pale-pink-coloured granite of the Belle Hougue type occurs as discontinuous sheets and lenses within the diorite, close to the entrances to the caves (Photo 3). The granitic rocks vary both in the proportions of potassic and plagioclase feldspars and also in the amount of quartz present. Most are classified as adamellites, with the quartz-poor varieties classified as monzonitic, and potassic feldspar-rich examples have a granophyric texture.

Unfortunately, most of the fresh bedrock surfaces around the Belle Hougue caves are sheer cliffs and impossible to access (Photos 1 and 2). Other exposures above the high-tide mark are covered by moss and lichen, and many of the intertidal exposures appear to be covered by algae and barnacles. However, some fresh rock surfaces, exposed on the promontory at the eastern edge of the Belle Hougue site, provide examples of the dark-coloured, fine-grained, altered diorite (Photo 4) and of the coarse-grained, feldspar-rich, pink-coloured Belle Hougue type of granite (Photo 5).

Age of the Belle Hougue igneous complex

A small outcrop of diorite and granite (the latter described as being 'syenitic' locally) at Belle Hougue Point has been referred to previously as the Belle Hougue igneous complex (IGS, 1982). The rocks here have not been dated directly, but close proximity to the eastern part of the *North-west igneous complex* and broad lithological similarities with the rocks there suggest that the *North-west igneous complex* and the Belle Hougue igneous complex are related.

A U-Pb zircon age of *c.* 483 Ma for a sample of St Mary's granite from Mont Huelin Quarry in the west part of Jersey, within the outermost zone of the main crop of the *North-west igneous complex* (Miller *et al.,* 2001), confirms that it was emplaced in the Ordovician Period.

Quaternary Sediments

Background

The caves at Belle Hougue are the objects of principal scientific interest at the site and are the reason for its current designation as an SSI site of international status (Nichols and Blampied, 2016). The history of the discovery and subsequent scientific investigations of the caves and their important features is fully described by Mourant (1984) and reproduced on the *Island Wiki* website:
https://www.theislandwiki.org/index.php/The_discovery_of_the_Belle_Hougue_cave.
Mourant details the fortuitous discovery of the larger cave (now known as Belle Hougue I) in 1914 by Father H Morin. Father Morin was walking along the top of the cliffs at Belle Hougue Point with a party of students when the hat of one of the students was blown off his head and into a fissure near the base of the cliff. When the student retrieved his hat, he reported that he had found a cave containing stalactites and had collected a mammalian vertebra. Further exploration was carried out, but this was soon interrupted by the outbreak of World War I. However, in 1917 and early in 1918, Father Morin returned to Jersey, reported his finds and handed most of them over to La Société Jersiaise. These included the bones and antlers of deer, numerous marine shells embedded in a calcareous cement and a single probable stone implement.

The deposits from this cave have since been the subject of intensive research by a long succession of specialists, e.g., Zeuner (1946), Keen (1975, 1978b, 1983, 1995), Keen *et al.* (1981), Hollin *et al.* (1993) and Lister (1989, 1993, 1995). The account by Mourant (1984) stated the following: 'The general conclusion was that the cave was hollowed out by the sea before or during the last warm stage but one. The sea was then some 18 m higher than at present, and a deposit of beach pebbles was then laid down on a shelf at this level in the cave, probably some 300,000 years ago. Then the sea retired far below its present level during the last cold stage but one, and returned during the last warm stage, about 120,000 years ago, to a height of about 8 metres above the present level.' This account differs, somewhat, from what is now understood about the Belle Hougue caves. In particular, it conflates the record of work at the Belle Hougue I cave with that from a second cave (Belle Hougue II), which first came to light when it was discovered in 1965 by R J Speller of the Jersey Rock Climbing Club. Speller reported it to the Société Jersiaise, saying that it contained raised beach pebbles and stalagmite deposits. This cave is some 30 m east of the main cave. A few months later, a party from the Société, including G Drew and A E Mourant, made a thorough exploration of Belle Hougue II. Drew had found a deer jawbone with teeth, and the party found numerous jaws, other bones and antlers, but no shells.

More recent studies are summarised by Bishop *et al.* (2003), who describe 'a complex of caves' between the two headlands at Belle Hougue Point; the most important of these caves, Belle Hougue I and II, contain raised beaches cemented by travertine. The beaches occur at the backs of the caves, at heights of *c.* 8 m a.m.s.l. The 8 m beach in Belle Hougue I contains nine species of marine molluscs, including the warm-water gastropod *Astralium rugosum*, indicating sea temperatures some 3–4°C above those of the present day. U-series dating of the travertine beach cement gave an age of 121 +14/-12 ka BP, and amino acid dating of *Patella* (limpet) shells from the beach gave an age of *c.* 120 ka BP. Both lines of evidence supported an Ipswichian (Eemian) warm stage (OIS 5e) age for the 8 m beach (Keen *et al.*, 1981). The bones of an extinct insular race of dwarfed red deer, *Cervus elaphus jerseyensis*, associated with the 8 m raised beach deposits (Lister, 1989, 1993), have been found in both the Belle Hougue I and II caves (Lister, 1995). This led Lister to conclude that the isolation of Jersey from the mainlands of France and England allowed the dwarfing (to half of the original size) of both modern and earlier Pleistocene forms to take place in as little as *c.* 6,000 years. This also suggests that Jersey was only isolated as an island during the period of the highest relative sea levels within the 10,000-year span of the last warm stage. This, together with the investigations of the Holocene sea levels in Jersey undertaken by Jones *et al.* (1990) and confirmed by Renouf (2015, figure 22), would indicate that much of the present-day submarine land surface between Jersey and France and Jersey and England was dry land throughout most of the Late Quaternary and early Holocene. Nichols

and Blampied (2016) also note that the faunal remains from the caves include hare and other small mammals, and that such remains can still be found today in the finer-grained cave deposits.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	No vehicle access
Safety of access	This site is not safe to access without an experienced guide and climbing equipment, as a steep cliff needs to be negotiated to access all of the caves.
Safety of exposure(s)	See above
Current condition	Most of the fossil remains have been removed from the site, although there is still the potential for further discoveries. Any search for more evidence should only be attempted in consultation with Jersey Heritage to insure the continued protection of this site.
Current conflicting activities	None known
Restricting conditions	These caves are naturally protected, as they must be accessed via steep cliffs.
Nature of exposure(s)	Caves and cliffs

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	This site is of continuing interest due to the two raised, wave-fashioned notches and the fossil-bearing lower raised beach. The latter has been proved to have a last interglacial age and contains a raised gravel beach partially cemented by travertine deposits; within these deposits, fossil remains, including antlers, teeth and bones from a now-extinct dwarfed species of red deer, and mollusca, have been preserved; these fossils are of international research importance given their context (HER Number 1200271). Flint flake (1200291).
Aesthetic landscape	This area is wild and unspoiled, so it is of significant aesthetic importance.
History of Earth science	One of only a few sites that preserve faunas from the last warm stage (Ipswichian)
Economic geology	None

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology	Regional	Good	Detailed descriptions	X
Prehistoric remains				

Geoscientific Value of the Site

Although they are difficult and dangerous to access, the caves at Belle Hougue Point are of major scientific importance, not only in the story of the Quaternary history of the Island but also for understanding the environmental conditions of the surrounding parts of Europe during the last warm stage period between *c.* 116–126 ka BP. The dating of the calcareous 8 m raised beach deposit in Belle Hougue I, using U-Th and amino acid dating, provided the only definitive age not only of any raised beach sequences in Jersey but also in the wider Normanno-Breton Gulf and adjacent areas north and south of the Channel (Jones and Keen, 1993). It also provided a clear indication of the height of the relative sea level during the last warm stage, while the presence of warm-water marine gastropods, indicating sea-water temperatures of 3–4°C above those of the present day, provide a clear indication of the climate in Jersey during that warm stage. The dating of the raised beach also provides a critical data point in the quest to establish a more detailed chronostratigraphical and lithostratigraphical correlation of the complex head-loess-beach sequences within Jersey, and it can help to correlate the Jersey sequences with similar successions from Normandy, Brittany and further afield in North-west Europe (e.g., Renouf, 2015).

The dwarfed red deer fossils from the site described by Zeuner (1940, 1946) and later by Lister (1989, 1993, 1995) led the latter to elucidate the importance of the isolation of Jersey, which was an Island for an estimated 6,000 years, in leading to the rapid evolution of a new dwarf species; full-sized equivalents were present in fossil assemblages throughout North-west Europe both before and after the warm stage. It also highlighted the relatively short period of time, prior to the Holocene rise in sea level (which reached its maximum around 4,000 yr BP), that Jersey was not connected to the mainland of continental Europe or Britain by land crossings over the last *c.* 126,000 years.

The report by Bishop *et al.* (2003) discusses a fragmentary example of the 18 m raised beach, with a calcareous cement, in Belle Hougue II. This would have provided a unique future opportunity to attempt to date this deposit and further elucidate the Quaternary sea-level story, both in Jersey and in the surrounding region. There are, however, no known beach deposits left in the cave.

Assessment of Site: Current Site Usage	
Community	A local RIB tour provider, Jersey Seafaris, passes the site on their North Coast tour.
Education	Known to have been visited by educational groups

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The caves are extremely susceptible to destruction by collectors.
Potential use	The site is of most use to academic researchers and the research community.

Site Photos:

Photo 1: View looking into the Belle Hougue caves; the view looks west from the promontory at the eastern edge of the site. The high, sub-vertical cliffs surrounding the site mean that the caves are best accessed by boat in calm seas. BGS © UKRI 2020.

Photo 2: Looking west into the Belle Hougue caves. Clean, sub-vertical surfaces reveal the dark-coloured basic and intermediate igneous bedrock of the Belle Hougue igneous complex. Unfortunately, most of the bedrock surfaces above high tide are covered by moss and lichen (which look yellow and green in this image), and many of the intertidal exposures appear to be covered by algae and barnacles (which look black in this image). BGS © UKRI 2020.

Photo 3: The dark-coloured diorite and gabbro that make up much of the Belle Hougue igneous complex are intruded by pale-pink-coloured granite of the Belle Hougue type. BGS © UKRI 2020.

Photo 4: Close-up view of a relatively fresh surface showing the fine-grained, dark-coloured, dioritic igneous rock exposed on the promontory at the eastern edge of the site. BGS © UKRI 2020.

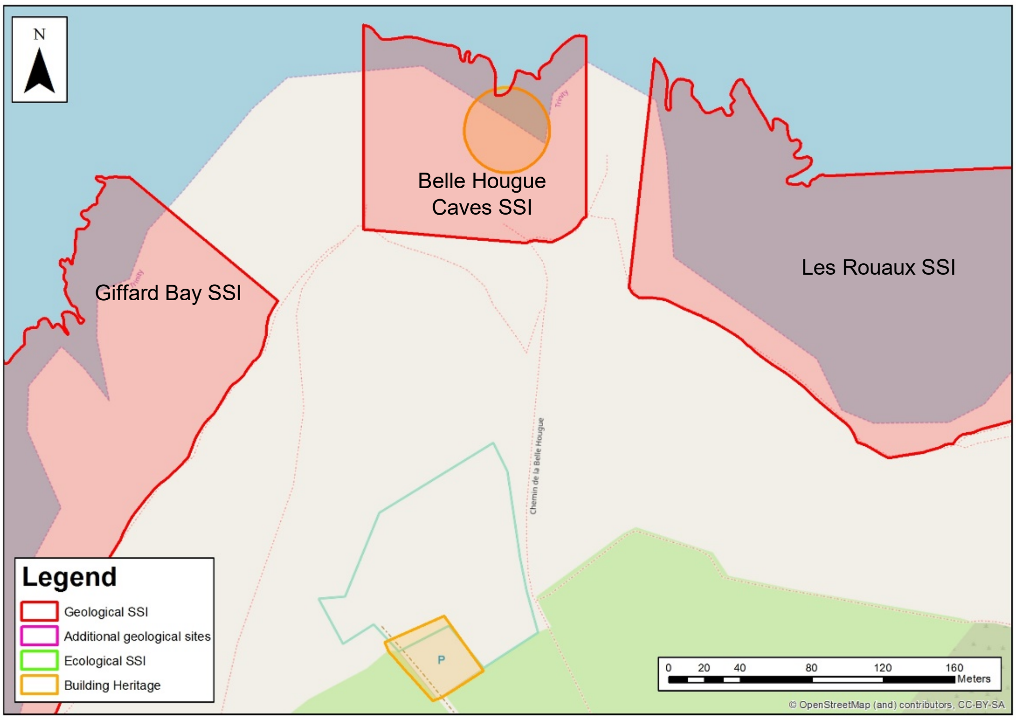
Photo 5: Close-up view of a relatively fresh surface showing the coarse-grained, pink-coloured granitic rock (probably Belle Hougue granite) exposed on the promontory at the eastern edge of the site. BGS © UKRI 2020.

Photo 6: Section through head deposits close to the footpath above the Belle Hougue caves. BGS © UKRI 2020.

Photo 7: Close-up of the head deposits above the Belle Hougue caves. BGS © UKRI 2020.

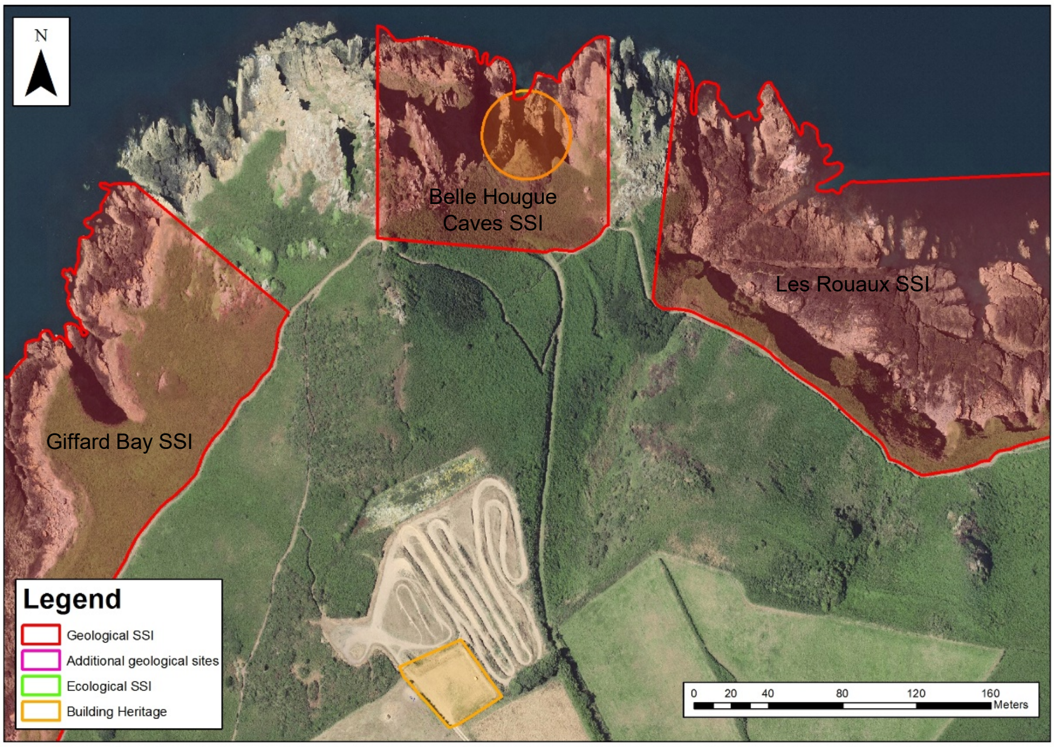
Photo 8: View looking north-west from the Belle Hougue site. The Islands of Sark and Guernsey can be seen on the horizon. The bedrock outcrops in the foreground are typically covered in moss and lichen. BGS © UKRI 2020.

Map of the site boundary on a topographic base



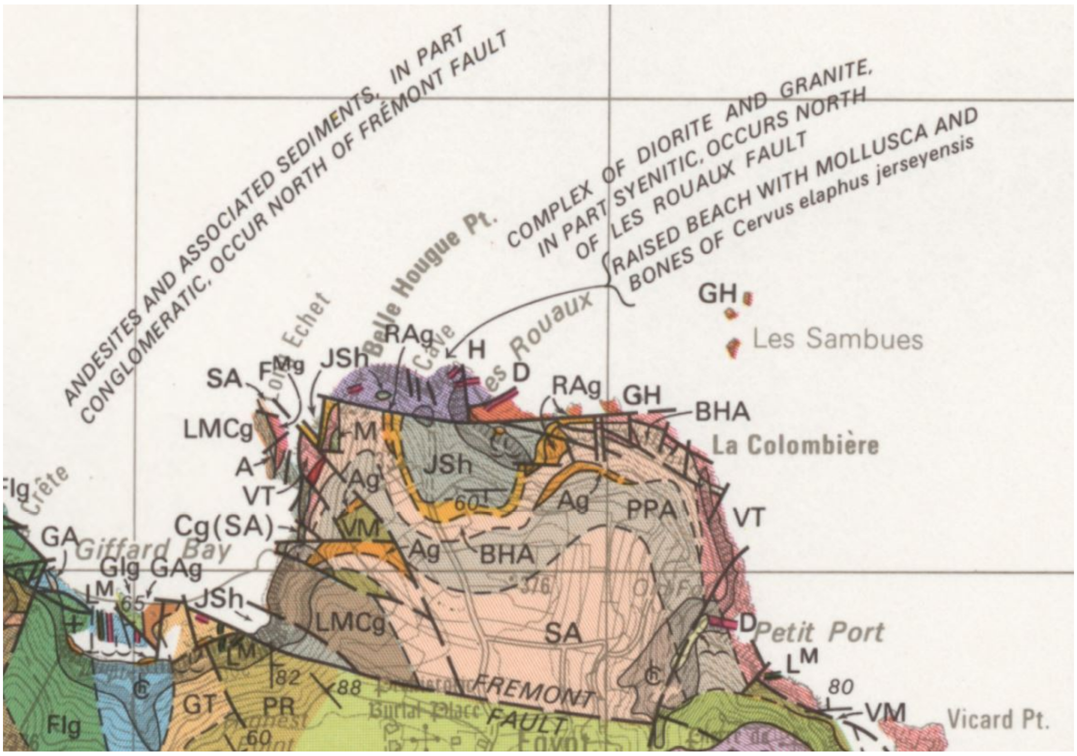
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

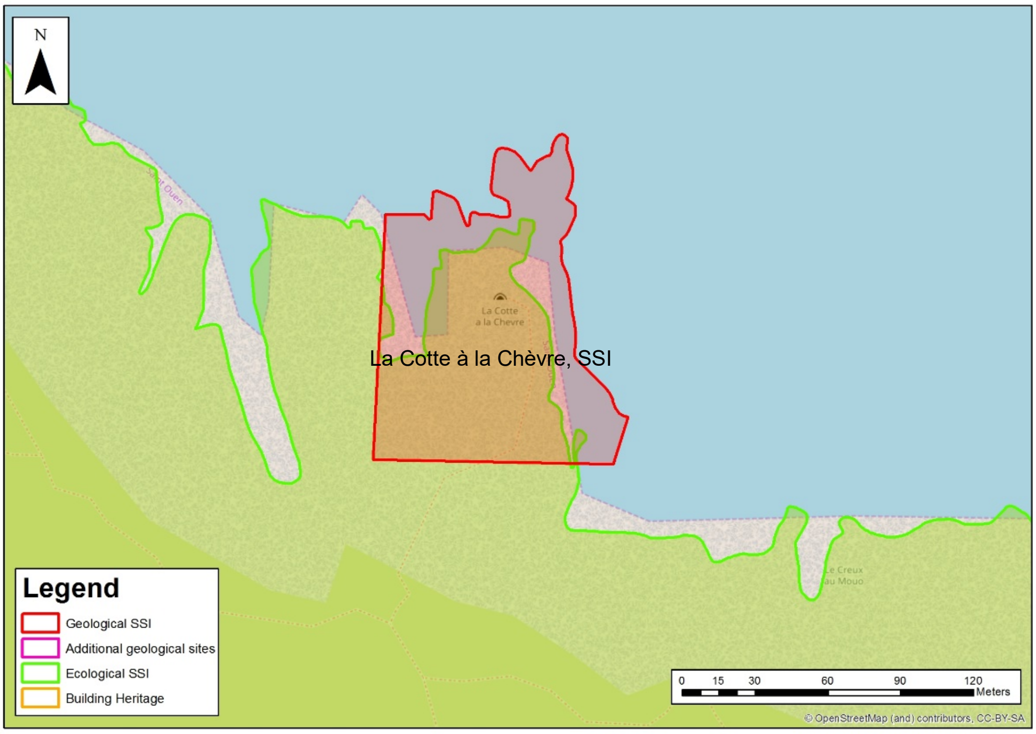


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

7.19 SITE NAME: LA COTTE À LA CHÈVRE, SSI

Site Information:	
La Cotte à la Chèvre is a sea cave on the north-west coast of Jersey. The site is of particular importance because it was the site of historic archaeological investigations, which produced worked flints and evidence of fires, assumed to be created by Palaeolithic hunters. The cave was likely developed by erosion when the sea level was higher, and it is perhaps associated with the 14 m level identified elsewhere on the Island. Although historic excavations have destroyed much of the prehistoric evidence, the site remains important for teaching.	
National Grid Reference: Mid-point: 32318, 73644 West end: 32271, 73649 East end: 32374, 73608	**Site Type:** Natural exposure, natural landform
Site Ownership: To be confirmed	**Current Use:** Open country
Field Surveyors: This site was not visited by BGS.	**Current Geological Designations:** Geological SSI
Date Visited: This site was not visited by BGS.	**Other Designations:** The Geological SSI overlaps with Les Landes Ecological SSI and Les Landes Prehistoric Landscape.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Upper Cambrian to Ordovician	**Formation:** St Mary's granite of the *North-west igneous complex*
Rock Types: Dominantly granite	

Site Description:

Introduction

La Cotte à la Chèvre is a sea cave on the north-west coast of Jersey. The site is of particular importance because it was the site of historic archaeological investigations, which produced worked flints and evidence of fires, assumed to be created by Palaeolithic hunters. The cave was likely developed by erosion when the sea level was higher, and it is perhaps associated with the 14 m level identified elsewhere on the Island.

Bedrock Units

St Mary's granite of the North-west igneous complex

The cave has developed in St Mary's granite, which forms the outer zone of the *North-west igneous complex*. St Mary's granite is coarse-grained; it contains tabular crystals of orthoclase with subordinate or smaller plagioclase, abundant quartz, biotite and hornblende. Zircons and apatite are also common accessory minerals. The rocks tend to be a greyish pink because of the presence of small, chloritized biotite crystals (Bishop and Bisson, 1989).

The *North-west igneous complex* has a concentric or 'bullseye' pattern: there is an outer zone of 'coarse granite', a middle zone of 'porphyritic granite' and a small central zone of 'biotite microgranite' (Bland, 1985; Brown *et al*., 1990). This pattern suggests that the *North-west igneous complex* is a single concentrically zoned pluton. Extensive outcrops along the north-west coast of Jersey present excellent examples of all the main components of the *North-west igneous complex*; the sites at **Le Pinacle** and **Le Pulec** provide accessible examples of rocks forming the outer zone of *St Mary's granite*, while the **Sorel Point** site provides superb examples of rocks formed by the interactions of siliceous and basic magmas.

Age of the North-west igneous complex

A U-Pb zircon age of *c.* 483 Ma for a sample of *St Mary's granite* from **Mont Huelin Quarry** (Miller *et al.,* 2001), in the outermost zone of the pluton, confirms that the *North-west igneous complex* was emplaced in the Ordovician Period. As such, it is around 100 million years younger than the other two main igneous complexes in Jersey (*South-west igneous complex* and *South-east igneous complex*). The cause of the magmatism that produced the *North-west igneous complex* is not clear, but it may be related to a late Cadomian event or it may have been linked to widespread tectonic events around the Iapetus and Rheic ocean realm at this time.

Prehistory

La Cotte à la Chèvre (also referred to in the literature as La Cotte de St Ouen) is a small sea cave, measuring 9 x 5 m, located on the granite headland of Jersey's north-west coast. The archaeological material excavated from the site is predominantly composed of lithic artefacts made from flint; however, rare fragments of faunal remains have also been observed in the museum collection. The lithic assemblage is extensive, amounting to approximately 16,000 stone artefacts (calculated via weight); the morphology of these artefacts appears to resemble Middle Palaeolithic technologies made by Neanderthals; for example, the Levallois technique is present. Several finds that can be dated to the Mesolithic and Upper Palaeolithic also exist, although they may derive from the headland above the cave. Due to the proportion of artefacts displaying Middle Palaeolithic technology, it is likely that this site was occupied or visited by Neanderthals during the Middle Pleistocene. Although no radiometric dating has been carried out, the cave is located on the 18 m raised beach, and it has been suggested that it formed during a number of later Middle Pleistocene high sea stands, with the most recent being formed in Marine Isotope Stage (MIS) 7, implying that any occupation took place after this time. When compared to the record at the nearby La Cotte de St Brelade, where an extensive Neanderthal presence existed during conditions of lowered sea level, it appears likely that visitations to La Chèvre took place at a similar time, perhaps during MIS 7–6 (around 250,000 years ago). Due to the steep offshore topography surrounding the site, a significant fall in sea level would have been required to open up the landscape for subsistence. This further suggests that the site was occupied during cooling or warming intervals when the terrestrial area was larger and included channels, rivers and valleys.

The site was first discovered by Joseph Sinel and Samuel Dancaster in 1861, but formal excavation did not begin until the turn of the century. This fieldwork was initially led by the original finders but continued under the supervision of Robert Marett (1911–1912) and later under Professor Charles McBurney (1962–1968). Between these excavation seasons, the cave was visited by other archaeologists, for example, Professor Friedrich Zeuner and Jacquetta Hawkes. As noted, the early excavation seasons involved the removal of a large amount of archaeological material in a relatively unstandardised manner. This resulted in a collection in which the majority of artefacts do not have a direct provenance within the site and its stratigraphy, a factor that has greatly affected the site's impact on the wider Middle Pleistocene archaeology of the region. However, a recent re-evaluation of the material excavated by McBurney has revealed some trends in lithic technology within the reconstructed stratigraphy, for example, the dominance of small debitage in the lowest archaeological layer. This also relocated the only bifacial tool found at the site, a small cordiform hand axe, which is now found in the Jersey Museum. Despite this work, the initial positions of much of the collection remain unknown, but the number of finds and their place within the prehistory of Jersey mean that the La Chèvre site remains of great importance and may benefit from further study.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	No vehicle access
Safety of access	Access should only be attempted with an experienced guide.
Safety of exposure(s)	Steep, near-vertical drops at the side of the footpath
Current condition	This site has been extensively excavated in the past.
Current conflicting activities	Visits from tourists and teaching groups may further erode any remaining archaeological evidence.
Restricting conditions	None
Nature of exposure(s)	Cave in exposed, sheer cliffs

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	This site has been visited and documented in books and the academic literature for more than 100 years. La Cotte à la Chèvre is a Middle Palaeolithic occupation site (HER Number 0900344; Listed place OU175). La Hougue de Grosnez is a mound, *c.* 15 m in diameter and 0.9 m high, covering the remains of a ruined stone structure, represented by four recumbent boulders between 0.8 m and 1.2 m long. This dates to the Neolithic period, *c.* 3500–2000 BC (HER Number 0900345; Listed place OU175). Les Landes Area of Prehistoric Activity is an important prehistoric landscape with archaeological sites from the Palaeolithic, Mesolithic and Neolithic. It is of outstanding importance to the archaeological heritage of Jersey and includes evidence of importance to European prehistory (HER Number 0900175; Listed place OU175).
Aesthetic landscape	The cave is in a section of very wild and picturesque cliffs.
History of Earth science	Not known
Economic geology	None

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology				
Prehistory	Regional	Moderately good	Detailed descriptions	X

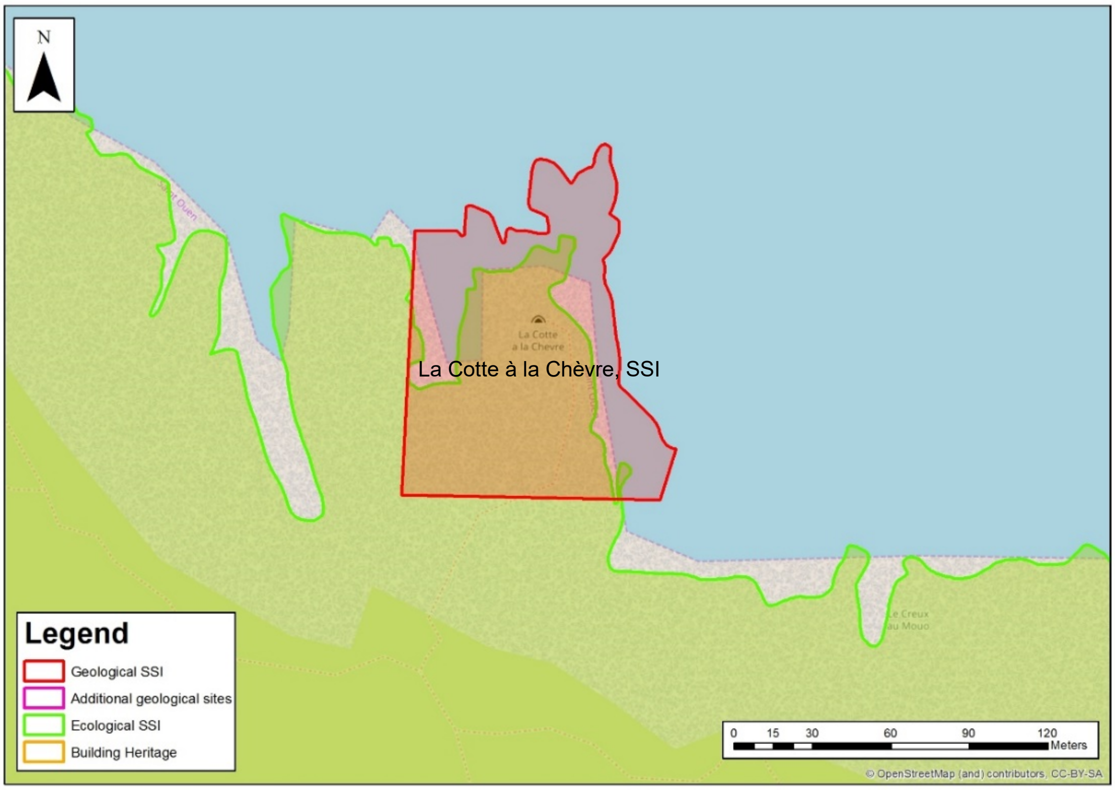
Geoscientific Value of the Site

La Cotte à la Chèvre is of particular importance because it has been the site of historic archaeological investigations, which produced worked flints and evidence of fires, assumed to be created by Palaeolithic hunters. The cave was likely developed by erosion when the sea level was higher, and it is perhaps associated with the 18 m level identified elsewhere on the Island.

Assessment of Site: Current Site Usage	
Community	None known
Education	It is used by local educational groups and is particularly useful for discussing palaeo-sea-levels.

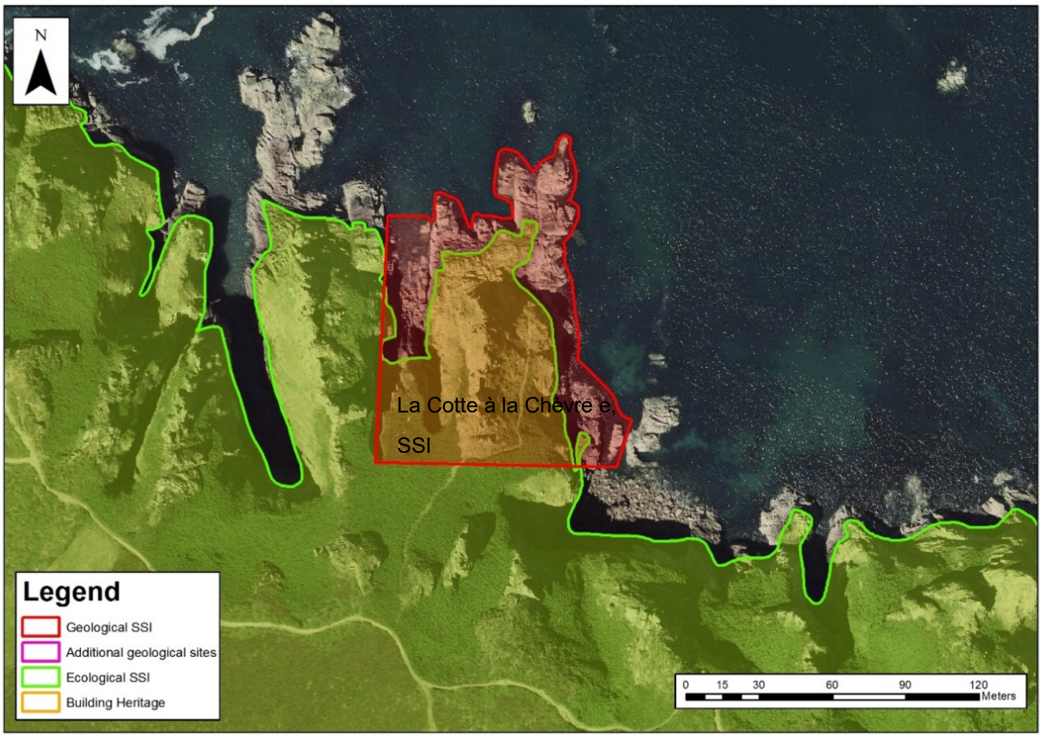
Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Although much of the archaeological evidence at this site has been lost, there is the potential for further work.
Potential use	Teaching the public about prehistoric man and palaeo-sea-levels

Map of the site boundary on a topographic base



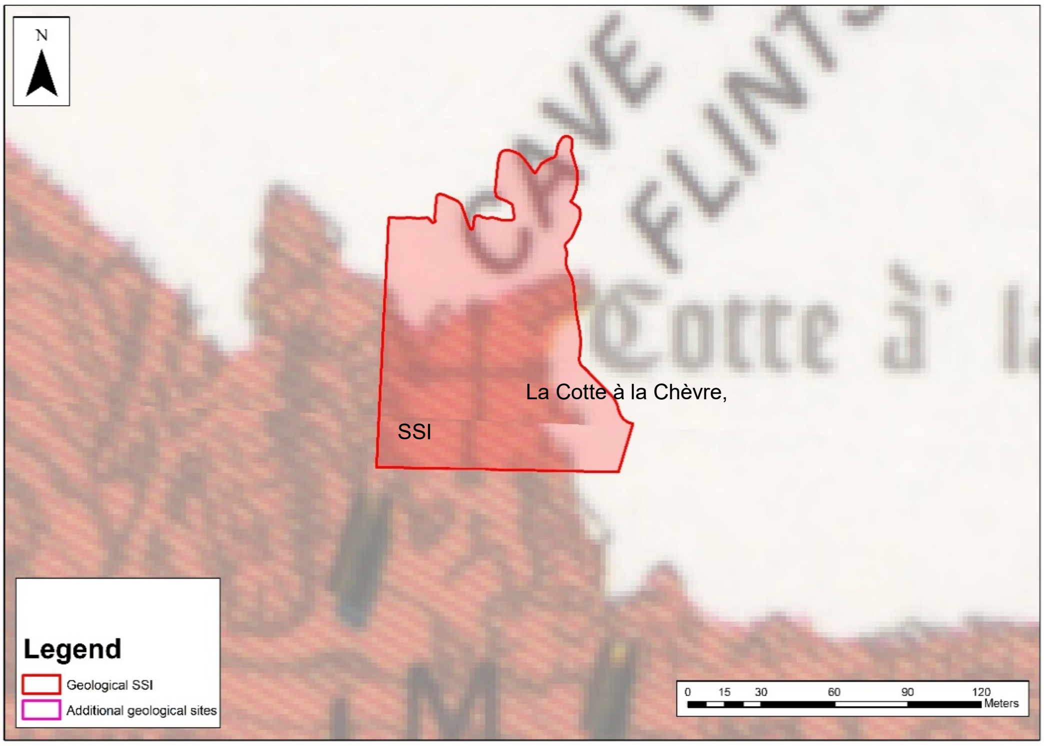
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Map of the site boundary on a published geological map

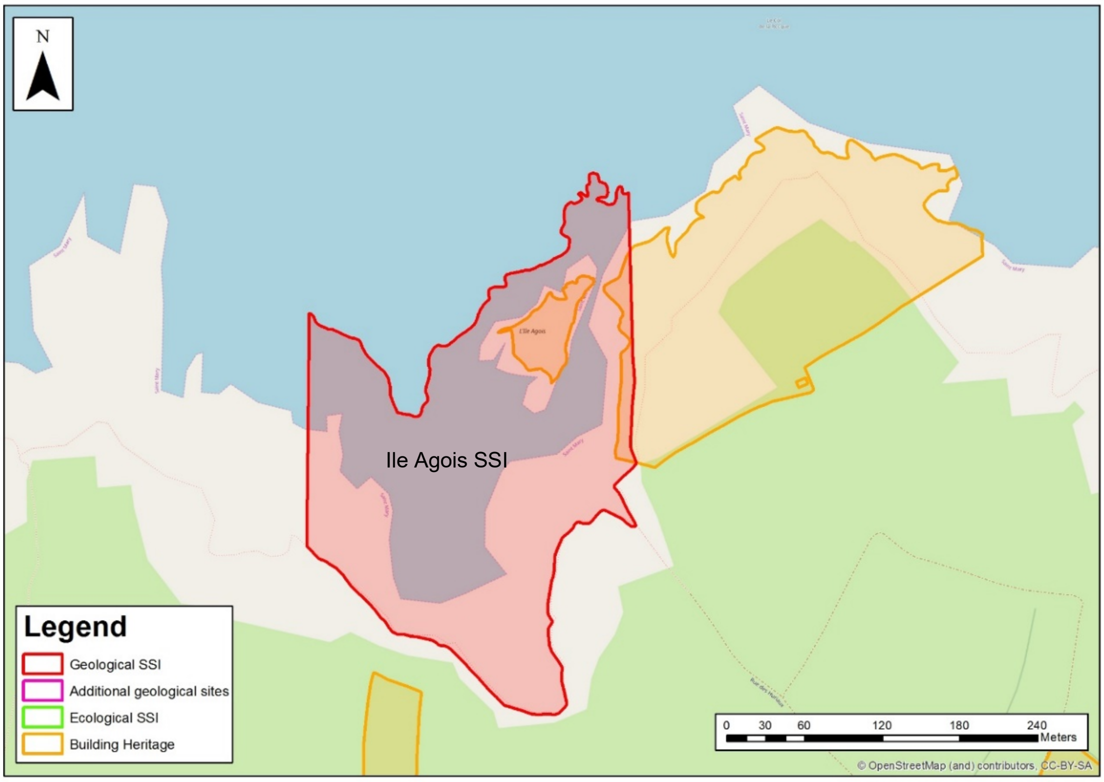


Reproduced from IGS (1982).

7.20 SITE NAME: CRABBÉ AND ILE AGOIS, SSI

Site Information:	
This site comprises a *c.* 1 km section of coastal cliffs, headlands and bays from Devil's Hole to Crabbé. Wave-cut notches from remnant raised shorelines at the 8 m and 18 m levels can be observed, along with a through cave known as Devil's Hole. The coastline is cut into the *North-west igneous complex*. The sea stack of Île Agois itself supports significant Iron Age and Early Medieval archaeological remains.	
National Grid Reference: Mid-point: 36538.831, 72554.249 West end: 36388.293, 72590.112 East end: 36623.244, 72725.049	**Site Type:** Coastal bedrock cliffs, back scarps and headlands. Natural section/exposure
Site Ownership: Part National Trust for Jersey and part public	**Current Use:** Open Country, coastal path
Field Surveyors: J Everest and L Hughes	**Current Geological Designations:** Geological SSI
Date Visited: 25 September 2019	**Other Known Designations:** The eastern margin of the SSI overlaps with a Building Heritage designation.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Upper Cambrian to Ordovician	**Formation:** *North-west igneous complex*
Rock Types: The cliffs are comprised of pinkish-grey granite with dark grey gabbro, grey diorite and white quartz.	

Site Description:

Introduction

This site comprises a 1 km section of granite coastal cliffs that are around 30 m high, with several embayments and structurally controlled weathered gullies. Visible along the clifftop path to the west of Crabbé, the coastline displays distinct notches, reflecting palaeo-erosion surfaces at the 8 m shoreline; there are also notches representing the 18 m shoreline (Photos 1 and 2). Evidence of erosion at higher levels than erosion today is also evident in vertically eroded gullies, which are the result of the erosion of dolerite dykes and faults within the granite bedrock by the sea at the 8 m level, most likely during the Ipswichian (*c.* 120 ka BP; Renouf and James, 2011).

Separate from the coastline is the sea-stack of Ile Agois, a site of archaeological importance with evidence of former settlements on the level ground at its top. The site is reported to have been occupied both during the Iron Age (800–55 BC) and the Early Medieval period (7th or 8th century AD), when an early Christian monastery was established on the stack, as shown by the remains of a large number of semi-circular huts built on artificial terraces on the summit of the stack. To the east of Île Agois is Devil's Hole, a contemporary through cave formed of a collapsed cave previously called 'Spiral Cave' (Photos 3 and 4). The route to Devil's Hole is well signposted, with a clear pathway indicated from the car park at the Priory Inn.

Bedrock Units

St Mary's granite of the North-west igneous complex

The cave has developed in St Mary's granite, which forms the outer zone of the *North-west igneous complex*. At this site, the St Mary's granite is porphyritic (Bishop and Bisson, 1989). Two main components of the *North-west igneous complex* were distinguished on the geological map of Jersey (IGS, 1982) – *St Mary's granite*, which forms more than 90% of the onshore outcrop, and *Mont Mado granite*, which underlies a sliver of ground at the eastern extremity of the outcrop. Subsequently, the outcrop of *St Mary's granite* has been divided into several components distinguished by their textural and/or mineralogical characteristics. They are distributed in a concentric or 'bullseye' pattern: there is an outer zone of 'coarse granite', a middle zone of 'porphyritic granite', as seen at **Ile Agois**, and a small central zone of 'biotite microgranite' (Bland, 1985; Brown *et al*., 1990). This pattern suggests that the *North-west igneous complex* is a single concentrically zoned pluton. **Le Pinacle** and **Le Pulec** provide accessible examples of rocks forming the outer zone of *St Mary's granite*, while the **Sorel Point** site provides superb examples of rocks formed by the interactions of siliceous and basic magmas.

It is interesting to note that the term 'Jerseyite' was coined for a lamprophyre from this site. It referred to a quartz-bearing variety of minette, although the term is no longer in general use (Velde, 1970).

Age of the North-west igneous complex

A U-Pb zircon age of *c.* 483 Ma for a sample of *St Mary's granite* from **Mont Huelin Quarry** (Miller *et al.,* 2001), in the outermost zone of the pluton, confirms that the *North-west igneous complex* was emplaced in the Ordovician Period. As such, it is around 100 million years younger than the other two main igneous complexes in Jersey (*South-west igneous complex* and *South-east igneous complex*), and it is not related to them or to the Cadomian Orogeny.

Quaternary Sediments and Landforms

The Quaternary landscape and environment of Jersey is dominated by the interplay between periods of erosion and deposition in response to changes in the climate and local sea-level change. During the various changes in the base level caused by rising and falling oceans, cyclical periods of erosion and deposition occurred around coastal areas and valleys. During the cold stage, periglacial conditions dominated North-west Europe, and like the wider region, the Island endured a cold and arid climate with little vegetation to anchor sediments.

The evidence of sequences of past high relative sea levels in Jersey, Guernsey and Alderney, on the Cotentin Peninsula and in Brittany is widespread. It includes notches and platforms cut into bedrock as well as raised beach remnants at a wide range of elevations above the present mean sea level. Currently, six separately distinguishable Quaternary high sea-level stands have been identified in Jersey by Renouf and James (2011); the 18 m and 8 m stands can be identified at Île Agois. There is also a composite, distinctly dipping notch composed of anastomosed higher and lower notches at about 8 m (information from J Renouf).

Crabbé and Île Agois are also notable for other geomorphological features. Île Agois is thought to have been isolated from the mainland by deep gullies and eroded by wave action, which exploited weaknesses in the bedrock. The development of the Île Agois sea stack along a NNE–SSW-trending fault was possibly initiated during the time of the 18 m high sea-level stand of Renouf and James (2011), as there is a notch visible here at this level. A notch at 8 m is also seen 10 m below. In the south-east corner of Ile Agois is an 8 m, wave-cut notch where the sea has eroded a cave or natural arch along a vertical dolerite dyke (Nichols and Blampied, 2016). On the cliff and coastal slope immediately opposite the western end of the south side of Ile Agois, there is a well-defined truncated valley descending from the plateau above (information from J Renouf).

There are a number of dykes and faults trending approximately NNW-SSE that are seen in the centre of the main cove at Crabbé, exposed at low tide. This includes a lamprophyre sheet, which is weak compared to the granite into which it is intruded. It is possible that these features were exploited by the sea to produce the cove. To the west of the cove, the 8 m platform is seen to have developed along an aplite (fine-grained granite) sheet (Davis, 1996).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Parking is available in a small car park to the east of Crabbé Rifle Range or in a larger car park by Priory Inn close to Devil's Hole. There is no direct access to the shoreline.
Safety of access	The coastal path is narrow and muddy in places; good footwear is advised.
Safety of exposure(s)	The geological features can only be viewed from above.

Access	Along the well-maintained and well-signposted narrow coastal path along the cliff top. Viewing from above only. The path is not suited to wheelchairs.
Current condition	The coastal path is in good condition; the rock-cut notches are also in good condition and are not thought to be at risk from erosion.
Current conflicting activities	This site is bordered by other conservation designations, although their presence is not thought to impact the site.
Restricting conditions	Firing range activity may occasionally limit access from the west along the coast path.
Nature of exposure(s)	Clifftop viewpoints along coastal path

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Noury described the dykes and geomorphological features in 1886. L'Ile Agois is a late Iron Age and early Medieval settlement site. The settlement is interpreted as an early Christian eremitic monastery (HER Number 0800071; Listed place MY0071). Le Col de la Rocque is an area of Mesolithic flint-working located on the northern coast of Jersey (HER Number 0800140; Listed place MY0140). Guardhouse is a ruined structure that is believed to be a guardhouse from *c.* the $18^{th}/19^{th}$ century; only a few examples survive on the Island (HER Number 0800133; Listed building MY0133). There are several lithic scatters (HER numbers: 0800165, 0800182-9, 0800194-5) and a dolerite axe (HER Number 0800157).
Aesthetic landscape	Coastal cliff views
History of Earth science	None
Economic geology	None

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology	Local	Moderately good	Referenced	X

Geoscientific Value of the Site
The geoscientific value of this site lies in the views of clear coastal erosional platforms that are linked to a history of archaeological settlement. It would be suitable for school groups that wish to view examples of raised coastal erosion features.

Assessment of Site: Current Site Usage	
Community	The shoreline is used by locals for general outdoor recreation purposes.
Education	The site includes views of coastal erosion features on palaeo-coastlines.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The geology is not thought to be fragile; however, the prehistoric remains are.
Potential use	This site could be used as part of a geotrail or for school trips and higher education and research.

Site Photos:

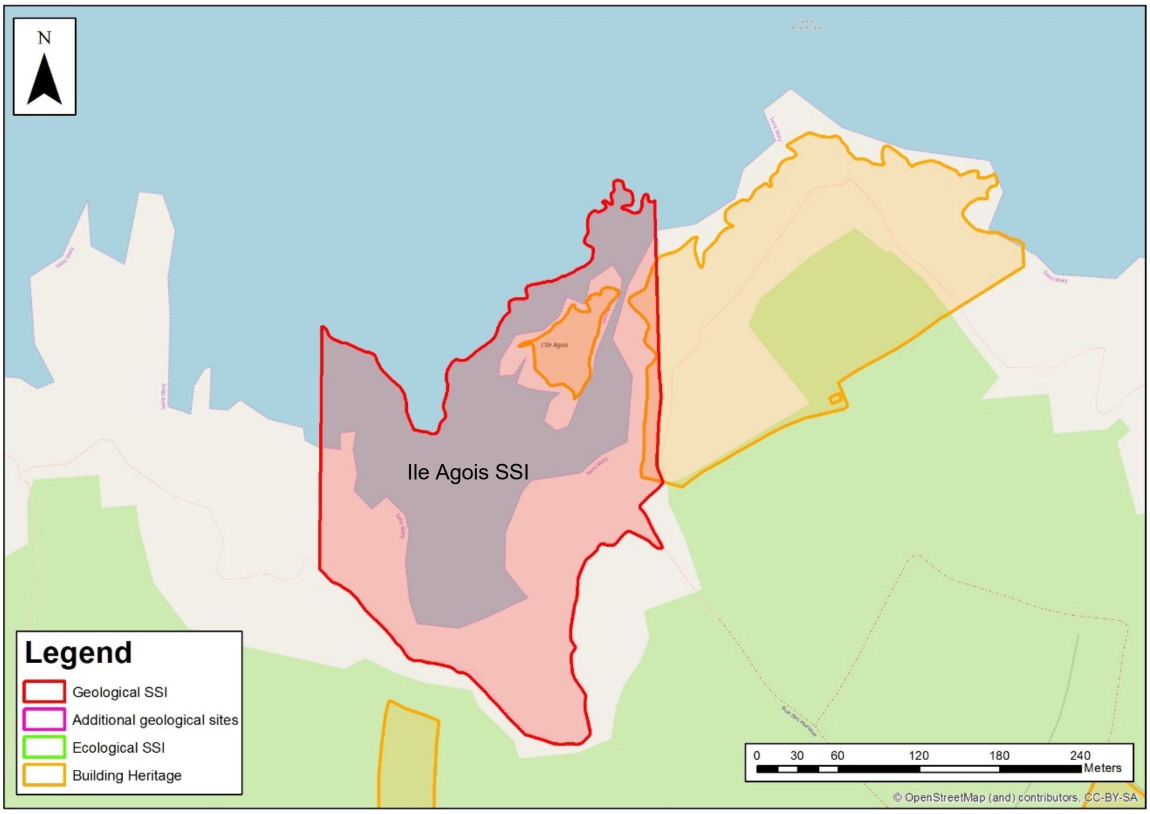
Photo 1: General view along the north coast looking westwards beyond Crabbe. Erosion platforms are visible at 8 m and 18 m.

Photo 2: Looking westwards along the coast path towards the sea stack of Ile Agois.

Photo 3: The viewing platform looking westwards above the Devil's Hole through cave.

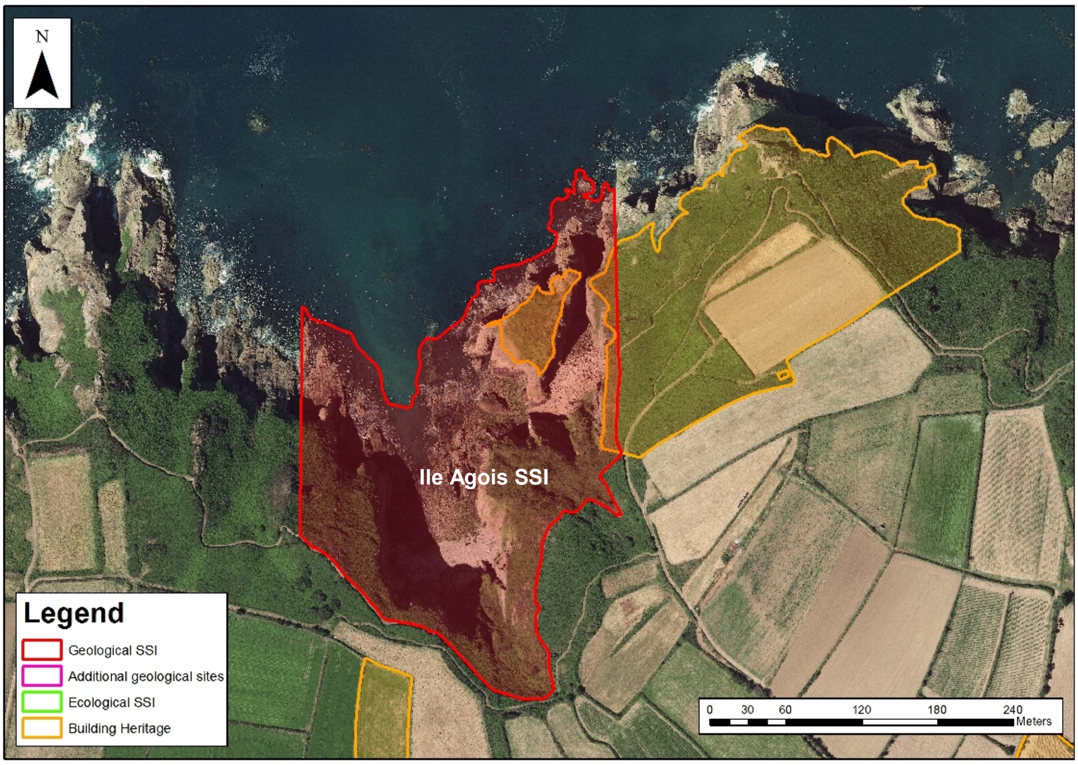
Photo 4: Devil's Hole through cave at low tide; the arch where water ingresses at high tide is visible.

Map of the site boundary on a topographic base



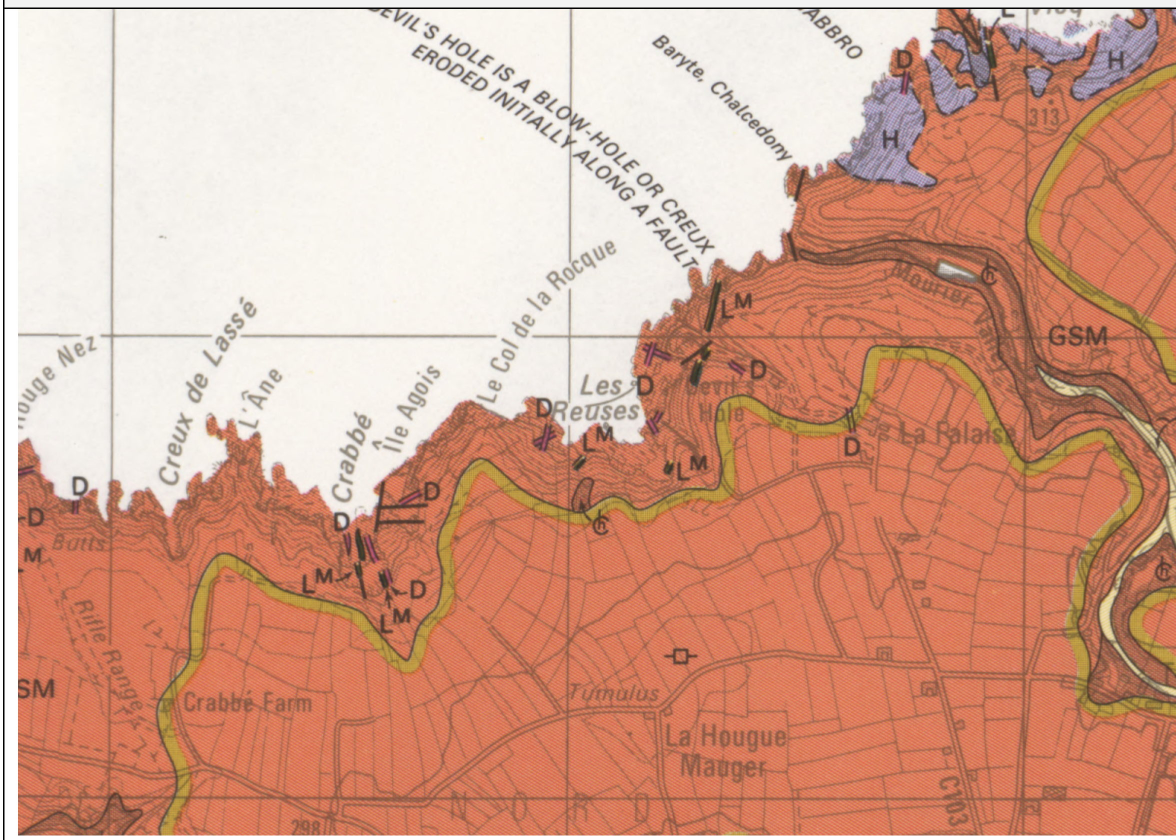
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

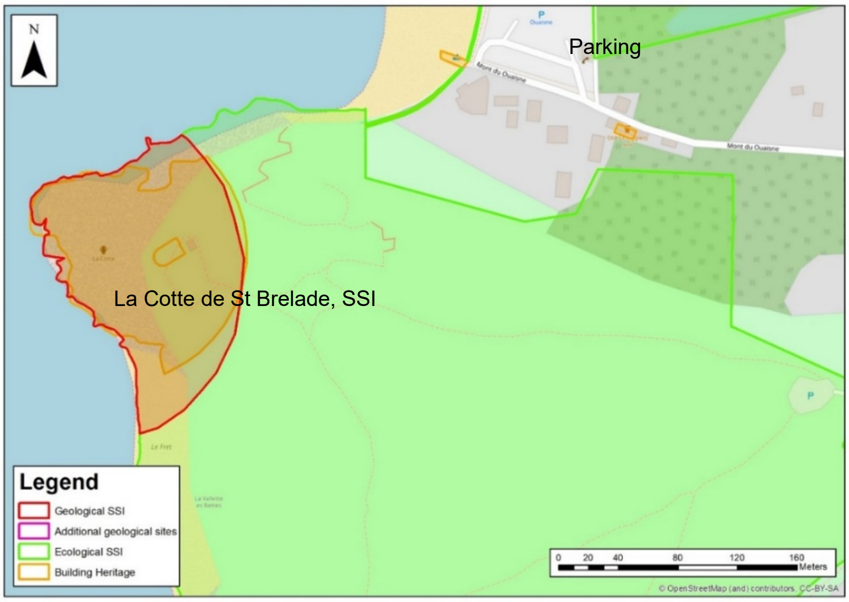


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

7.21 SITE NAME: LA COTTE DE ST BRELADE, SSI

Site Information:	
La Cotte de St Brelade is the most significant Quaternary site in Jersey. The site comprises a T-shaped ravine system within a granite promontory above the southern end of St Brelade's Bay, and since 1881, it has been the focus of archaeological research due to the abundant record of Palaeolithic artefacts and Pleistocene faunal remains that have been recorded at the site. The site is internationally important. Its importance is primarily due to the time-depth of the site: it contains successive Quaternary deposits spanning over 238,000 years and consequently preserves a regionally significant record of climate and environmental change. That these deposits also include a large collection of Middle Palaeolithic artefacts, butchered faunal remains and hominin fossils raises the site's importance to the highest level of significance for a site of this type. The site has been subject to severe erosion and loss over the past four decades, a process now being mitigated by engineering works funded by Jersey Heritage.	
National Grid Reference: Mid-point: 36134, 64499 West end: 36072, 64526 East end: 36215, 64487	**Site Type:** Deposits in ravine, revealing environmental, ecological and anthropogenic history throughout the Middle and Late Quaternary
Site Ownership: Part National Trust for Jersey and part Société Jersiaise	**Current Use:** Access closed
Field Surveyors: J Everest and L Hughes. Prehistoric notes by M Pope and M Bates. Additional photos by J Renouf	**Current Geological Designations:** Geological SSI
Date Visited: 24 September 2019	**Other Designations:** Listed Place, Grade 1 (La Cotte de St Brelade). Ecological SSI: Portelet Common

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Pleistocene	**Formation:** Loess
Rock Types: Silt	
Age: Pleistocene	**Formation:** Beach
Rock Types: Bouldery, cobbly and sandy	
Age: Ediacaran (Late Precambrian)	**Formation:** *South-west igneous complex*
Rock Types: Granite	

Site Description:

Introduction

The Quaternary deposits at La Cotte de St Brelade preserve a record of climate-driven environmental change alongside a record of early human occupation from *c.* 238 ka BP to the Holocene. The deposits are preserved in a T-shaped ravine system formed by a combination of marine and subaerial weathering processes that cut through a granite headland on the south-west coast of the Island (Figure 1). The West Ravine is open to the sea, while the North Ravine has an opening high up on the north site of the headland; to the south, the North Ravine is overarched by a rock overhang, which has influenced preservation at the site. The sequence of Quaternary deposits at the site, of which *c.* 40% have been removed during archaeological investigations over the past 140 years, are dominated by head and loessic deposits as well as probable palaeosols. Marine sediments ascribed to the last interglacial and the penultimate interglacial occur at the bases of the sequences in the West Ravine and North Ravine, respectively. The sequences in the North Ravine are relatively well understood; those of the West Ravine are only partially understood, and little or nothing is known about the South Ravine sequences. The deposits contain faunal remains in places, including those of mammoths, rhinoceros, horses, wolves, rodents, birds and humans. The human occupation record comprises more than 13 stratified accumulations of stone artefacts of Middle Palaeolithic character, alongside butchered animal bones and evidence of fire and bone structures. These signatures are largely assumed to have left by populations of *Homo neanderthalensis*, but records of more recent *Homo sapiens* populations, as well as those of possible shared ancestry, are also present (Compton *et al.*, 2021). La Cotte de St Brelade is unparalleled in northern France or Britain in terms of its time span and the richness of its Middle Palaeolithic and faunal records; it is consequently of great international significance and pivotal to the understanding of the human occupation record of the La Manche region over the past quarter of a million years. Its record of the human use of fire and the presence of two or more distinctive heaps of bone and human teeth from a population with apparent shared *Homo sapiens* and *Homo neanderthalensis* ancestry make it a key site for understanding human behavioural and biological evolution/adaptation. Despite extensive archaeological excavation, the site still preserves extensive deposits with archaeological and palaeoenvironmental potential (Figure 1), and so its importance remains undiminished. Continued marine erosion has required the initiation of a significant engineering and archaeological excavation programme by Jersey Heritage in the West Ravine to bring the site under management and protection. Due to the inherent dangers of the site, it is presently closed to the public and currently unsuitable for direct onsite interpretation. The site is of such importance and complexity compared to the other localities considered in this review that only a thumbnail sketch based on the huge body of available published material can be presented here.

Bedrock Units

South-west igneous complex

The sea cliffs at the La Cotte de St Brelade site are composed of porphyritic granite, which forms part of the *South-west igneous complex*.

The *South-west igneous complex* is one of three major intrusion complexes in Jersey. Three main components are apparently distributed in a concentric or 'bullseye' pattern (IGS, 1982): Corbière granite, which is by far the most extensive and underlies around 80% of the onshore outcrop, forms the outer zone; La Moye granite, which occupies a narrow belt roughly 250 m wide, forms the middle zone; and Beauport granite forms the small central zone. This pattern indicates that the *South-west igneous complex* is a single, concentrically zoned pluton. La Cotte de St Brelade is developed within La Moye granite, which is a porphyritic granite with megacrysts of potassium feldspar set in a finer-grained matrix. Also exposed along the foreshore, below La Cotte de St Brelade, is the Beauport granite, which is an evenly grained aplogranite that weathers to a deep red colour. Examples of the Corbière granite can also be found close to the slipway at Ouaisné; these examples are coarse-grained, equigranular granites.

At the mouth of the West Ravine, there are fine examples of mm-scale quartz ocelli on wave-smoothed surfaces. Just east of the main headland of La Cotte de St Brelade – on the way, across the rocks, to Ouaisné – a range of fault planes above tidal levels have several-cm-thick mylonite, usually of a slightly greenish tint; this is an important indicator of the fact that the granite has a more complex geological history than is readily appreciable.

A well-defined U-Pb zircon age of *c.* 580 Ma for a sample of Corbière granite from a disused quarry north of La Cotte, on the east side of Ouaisné (Miller *et al.*, 2001), confirms that the *South-west igneous complex* was emplaced during the Ediacaran Period (the youngest period of the Precambrian Era). It is related to the main plutonic injection stage of the Cadomian Orogeny. It is around 100 million years older than the *North-west igneous complex* and unrelated to it.

Quaternary Sediments

The Quaternary sediments at the La Cotte de St Brelade site were originally up to 40 m thick, and they are complex and only understood in part. Significant parts of the La Cotte sequence were removed by archaeological excavations undertaken before the Second World War (perhaps up to half of the original site volume), with only rudimentary recording and the selective recovery of artefacts and fauna. Other parts of the site have been removed by marine erosion. More systematic excavations between the 1950s and 1980s removed further large bodies of Quaternary sediment but with a higher degree of systematic recovery and recording. These excavations are, at present, only partially understood, and considerable work must be undertaken on extant collections to understand these past projects. Today, the site is no longer accessible by the public due to safety concerns. In the past, access to the site was possible via a cliff path from the plateau above or from the foreshore at low tide.

Excavations have focused on the accessible parts of the North Ravine, the West Ravine (Photo 4) and parts of the South Ravine, with most work centred on the area under the rock arch in the North Ravine, at its junction with the West Ravine. Up to 12 m of intact Quaternary sediments in the West Ravine, South Ravine and the extreme northern end of the North Ravine remain intact and are currently either minimally or poorly understood. From the area studied to date, it is understood that the site has been the focus of repeated cycles of marine erosion under interglacial conditions and periods of the accumulation of head deposits and loess, which formed under subaerial conditions during the onset and maxima of cold stages. Previous works have demonstrated that a deposit of marine cobbles assumed to comprise a warm-stage beach dating to part of Marine Isotope Stage 7 (a complex interglacial with more than one high sea-level peak) are present at the base of the explored sequence in the North Ravine. Above this marine deposit lies a series of up to ten separately recorded terrestrial deposits that are related to a variety of temperate and cold stage depositional environments, which in turn are related to the end of MIS 7 and the stadials and inter-stadials of MIS 6 (Layers H–A and Layers 3–6; Figure 2; Callow, 1993).

Considering this succession in more detail, the earliest sediments overlying the beach are water-lain silts (Layer H), followed by two granitic sand layers (Layers F and G) that are capped by a deposit comprised largely of burnt and weathered animal bone and a truncated forest soil (Layer E). The significant finds of highly structured accumulations of large mammal bones occurred at the junction between Layers A and 3 and Layers 5 and 6. These bone heaps were comprised predominantly of woolly mammoth and woolly rhinoceros bones. Further granitic sand layers (Layers C and D) complete this lowest succession of deposits but also provide the only relatively secure radiometric date from this part of the sequence, a thermoluminescence date from a burnt artefact of 238 ± 35 ka. The sediments of Layers F through C are overall indicative of cooling climates, which culminated in the deposition of the loess / loessic head sequences of Layers B through A and Layers 3 through 6.1. Within the top layers of 6.1, two truncated forest soils herald the closing stages of MIS 6 and the onset of MIS 5e interglacial events.

This sequence is believed to have filled the full extent of the ravine system due to the MIS 7 high sea-level event. However, it was then eroded out by the MIS 5e high sea-level event throughout much of the West Ravine up to a cliff line running east-west through the North Ravine and to an unknown degree into the South Ravine. Above the marine beach cobbles, which are related to the MIS 5e interglacial, lie sloping head deposits comprising granitic sands (7.2), which formed immediately in front of the cliff. These are in turn overlain by water-lain silts and dark-coloured humiferous deposits (Layers 8.3 and 9). There followed a rapid transition into the uppermost sediments (Layer 11), which comprise head material with coarse granite fragments but also, as recently proven by excavations in the last decade, sandy, gravelly deposits that extended out onto the newly created sedimentary platform in the West Ravine. The parts of the head succession excavated in the phase spanning the second decade of the 19th century contained major large and small mammal finds and an abundance of artefacts. Recent work in the West Ravine has demonstrated that sediments above the last interglacial beach range from around 100 to 47 ka BP.

Archaeological Records

The site contains an archaeological record of such a scale and complexity that it is beyond the scope of this document to describe it in meaningful detail. Today, it consists of over 100,000 stone artefacts recovered from a series of separate excavations from 1910 to the present day, but some 90,000 of these artefacts came from McBurney's season in the 1960s and 1970s. It is known that many artefacts would have been lost or discarded during early-20th-century work and that a significant number of artefacts from the 1910–1915 excavations were lost in the second half of the 20th century; those that remained were grouped together, and thus important stratigraphic information was lost.

The artefacts form a series of assemblages related to discrete but broadly discontinuous occupation episodes at the site during MIS 7, MIS 6 and parts of the last cold stage, MIS 3 (Figure 2). At least two major occupation horizons were documented for this latter period, and the recent dating of Devensian deposits in the West Ravine suggests that they may postdate 47 ka BP (Figure 3; Bates *et al.*, 2013).

With the exception of very small numbers of late Prehistoric stone artefacts recovered from Holocene deposits in the West Ravine, the entire assemblage is related to Middle Palaeolithic technologies, which involved working with a wide variety of raw materials to produce both standardised tools, including hand axes, and unmodified flakes (Callow and Cornford, 1986; Shaw *et al.*, 2016).

The artefact assemblages are found alongside varying quantities of animal bone; some of these bones show signs of butchery and others were intensively burned as fuel. In addition, at least two highly structured accumulations of large mammal bones were recorded at the site. With the exception of these two 'bone heaps', which were found at the junction between Layers A and 3 and Layers 5 and 6 (Scott, 1980; Scott *et al.*, 2014) and relate to the period of rapid cooling predating the temporary abandonment of the site, most occupation is consistent with the direct occupation of the site and its use as a living space, with carcass elements and other materials being brought to the site for processing, consumption and use.

The 1910 and 1911 excavations produced 12 human teeth, which were found together on a rock ledge in the North Ravine close to where it meets the West Ravine (Nicolle and Sinel, 1910). The 11 surviving teeth come from two individuals and exhibit morphologies that are found separately in the wider *Homo neanderthalensis* and *Homo sapiens* populations (Compton *et al.*, 2021). The findspot for these remains appears to be some 2–3 m higher in the sequence than the recently dated sediments that span 100–47 ka BP. The anatomical features of the teeth (Figure 4), combined with their apparent late age, close to the time when *Homo sapiens* were present in the region, raises the possibility that the population has a shared ancestry. A further human bone, a fragment of a child's crania found higher up in the West Ravine, has not been directly dated and could be related to either species. No Upper Palaeolithic material, which is typically found with populations of Homo sapiens (they replaced Homo neanderthalensis in the region), has been found at La Cotte.

Faunal and Palaeoenvironmental Record

La Cotte de St Brelade has also produced important records of ecological and environmental change, in addition to the long and broadly continuous sedimentary record of changing depositional environments. Despite the challenging preservational environment for fauna, mammalian bone is relatively well preserved throughout those parts of the La Cotte sequence spanning MIS 6 through MIS 3. No fauna is preserved in the presumed interglacial deposits of Layers H and G and fauna is only sparsely preserved in Layer F. The matrix of Layer E is almost entirely granulated bone, but very little is identifiable. The later MIS 6 layers preserved bone to a greater degree due to the higher input of loess into these units, indicating cold conditions and a low sea level. The fauna is consequently of a cold stage character, comprising woolly mammoths, woolly rhinoceros, bison reindeer, red deer, chamois, Irish elk, cave bears, wolves, Arctic fox and lemmings. Pollen is poorly preserved but adds to the general picture that Layers H–C are temperate in nature, while Layers B to 6.1 are broadly cold, a pattern that is repeated in presumed interglacial and cold stage deposits from the Late Pleistocene sequence (Scott, in Callow and Cornford, 1986).

Current Status

Excavations at the site were intentionally halted in the early 1980s. During the three decades from then until 2010, but especially since the early 2000s, Quaternary deposits and their associated archaeology, including sediments that are still *in situ* in the West Ravine (as well as the overburden of the sediments dumped from the Burdo and McBurney excavations), have been seriously eroded by marine action. The problem was only addressed in 2010 through the start of the current phase of work and funding. This has included an NERC urgency grant for determining the scope and nature of the deposits at risk. With the overall management of the site now passed from its owners, the Société Jersiaise, to Jersey Heritage, work has been initiated to enhance the long-term protection of the site (Pope, 2019). The present result is the installation of a high gabion wall across the West Ravine; it is hoped that this wall will stem the power of erosive waves, which reached, on occasion, up to 6–7 m above maximum normal high tide levels. In 2019, excavations were initiated to stabilise and record, through excavation, the deposits of the West Ravine behind the wall installation. It is hoped that these projects will do more than just protect the section from collapse; ideally, they will also determine the scale and nature of Palaeolithic occupation in the West Ravine, locate further late Neanderthal material and open the way for future work in the North Ravine. Here, it is imperative to determine the condition of MIS 7 and MIS 6 deposits, including the continuation of the bone heaps behind the concrete wall installed in 1980, and to assess the condition and impact of the partially collapsed 'Deep Sounding' at the base of the excavation here.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Parking at Ouaisné or Portelet Common car parks
Safety of access	Unsafe. Cliff collapse and tides
Safety of exposure(s)	Unsafe. Cliff collapse
Access	Not permitted
Current condition	Poor
Current conflicting activities	None known
Restricting conditions	See above
Nature of exposure(s)	Deep and steep section of Quaternary sediments within a coastal ravine

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Significant archaeological importance. La Cotte de St Brelade is a Palaeolithic occupation site and one of the most important Palaeolithic sites in Europe (HER Number 0100255; Listed place BR0255). Nearby La Cotte Battery is an 18th-century gun battery with a magazine/gunner's room; it is part of an Island-wide network of military fortifications from this period (HER Number 0100361; Listed building BR0361).
Aesthetic landscape	Scenic location
History of Earth science	Understanding of the hominid occupation of the region
Economic geology	The granite was historically quarried for stone.

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	National	Good	Descriptions	
Structural geology				
Palaeontology				
Geomorphology				
Prehistory	International	Excellent	Detailed	X

Geoscientific Value of the Site

The site is of value because of the examples it contains of the coastal geomorphology of coastal erosion and Quaternary sediments and environments. It is of exceptional international importance because it is North-west Europe’s richest Middle Palaeolithic site.

Assessment of Site: Current Site Usage	
Community	Not used except for clifftop walking
Education	Active research area, used by students and academics

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Very fragile
Potential use	Further investigation for dating would be valuable but dangerous.

Site Photos:

Photo 1: General view of the foreshore, facing south. BGS © UKRI 2020.

Photo 2: View of stack and fault-guided ravine to the south of La Cotte de St Brelade from the beach. No access due to ongoing archaeological assessment.

Photo 3: Examples of the three named granite types exposed on the foreshore. Left: Corbière granite, which is coarse-grained and equigranular. Centre: La Moye granite, which is a porphyritic granite with megacrysts of potassium feldspar set in a fine-grained matrix. Right: Beauport granite, which is an evenly grained aplogranite that weathers to a deep red colour.

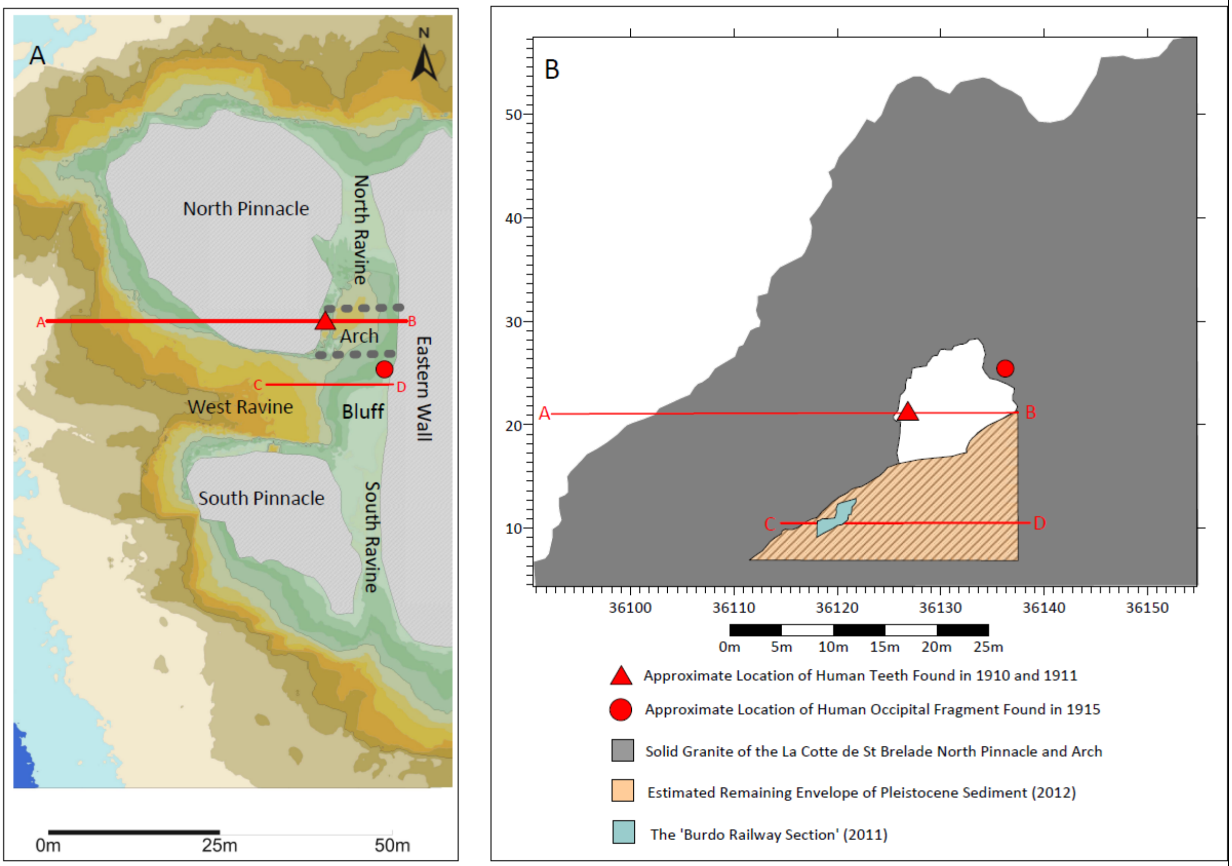
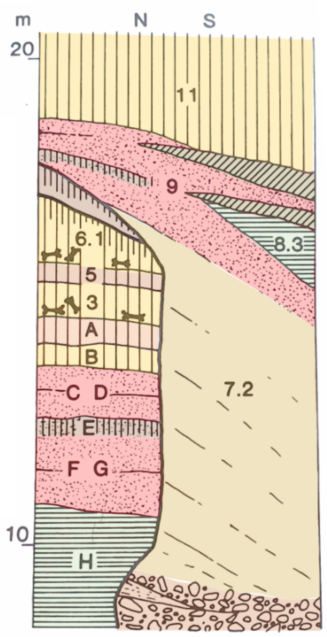


Figure 1: Map showing the structure of La Cotte de St Brelade and a schematic section showing the extent of surviving deposits in the West Ravine and the inferred position of human teeth and a human occipital fragment.



Layer	Member	Deposit Type	Inferred Climate	Inferred MIS	Archaeological Signature
H	Lower Granitic Sand	Water Lain Silt	Mainly Temperate	7	Dominated by notched pieces. Largely flint raw material
G/F		Granitic Sand	Mainly Temperate	7	Denticulate Middle Palaeolithic
E		Truncated Soil	Mainly Temperate	7	Rich in sidescrapers Large quantities of burnt bone
D/C		Granitic Sand	Mainly Temperate	7	Rich in sidescrapers. Proportionally more non-flint TL Date: 238K BP +/- 35,000
B	Lower Loess	Loess	Cold	6	Bone concentration. Sidescraper dominated with rare bifaces
A		Loess	Cold	6	Sidescaper dominated with rare bifaces. Increase in bone.
3		Loess	Cold	6	Lower Bone Heap at base. Abandonment.
5		Loess	Cold	6	Non-flint raw materials dominate. Rich in tools, including bifaces
6.1		Loess	Cold	6	Upper Bone Heap at Base. Abandonment
7.2		Talus	Mainly Temperate	5	Reworked artefacts from MIS 6/7 deposits
8.3	Upper Granitic Sand	Water Lain Silt	Mainly Temperate	5 to 3	Rare. Reworked.
9		Granitic Sand	Mainly Temperate	5 to 3	Rare. Reworked.
11	Upper Loess	Loess	Cold	3 to 2	Typical Mousterian. Rich in sidescrapers. Three levels. Rich in charcoal.

Figure 2: Schematic section through the stratigraphy of La Cotte de St Brelade. After Callow (1993).

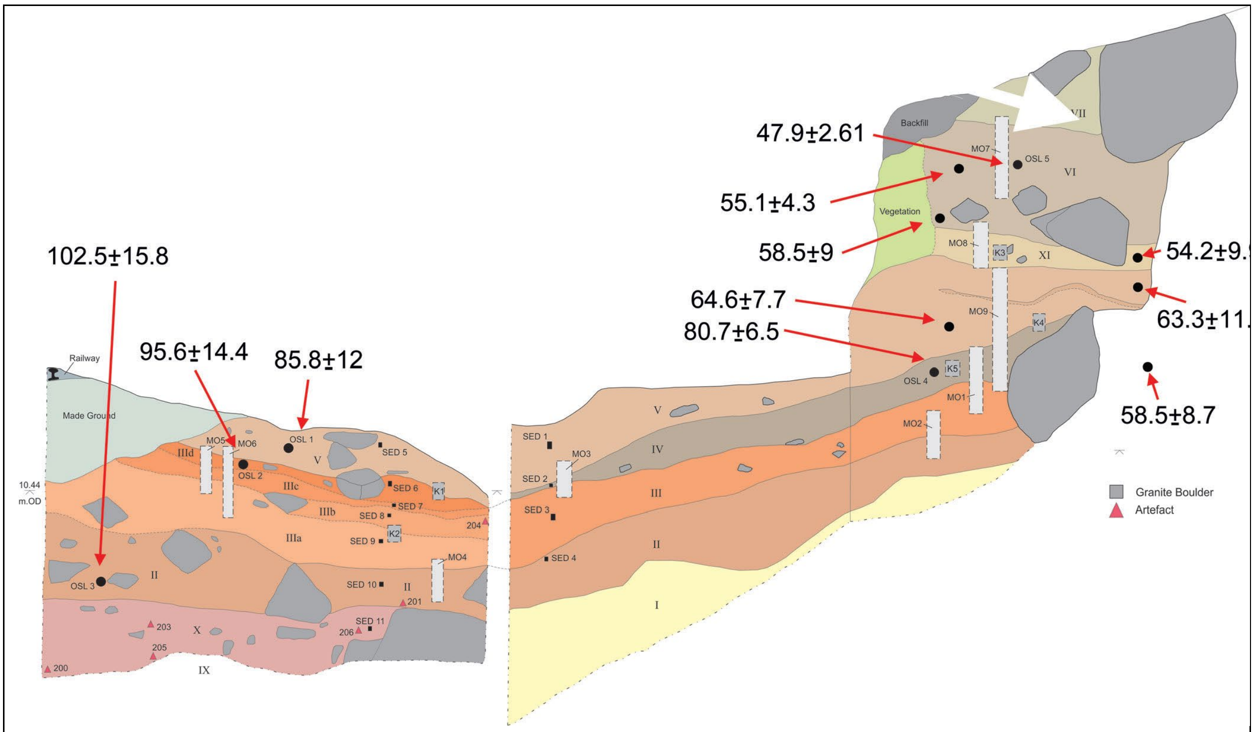


Figure 3: Dated sequence at the base of the West Ravine considered to be the equivalent of Callow's Units 7.2–9 (from Bates *et al.*, 2013).

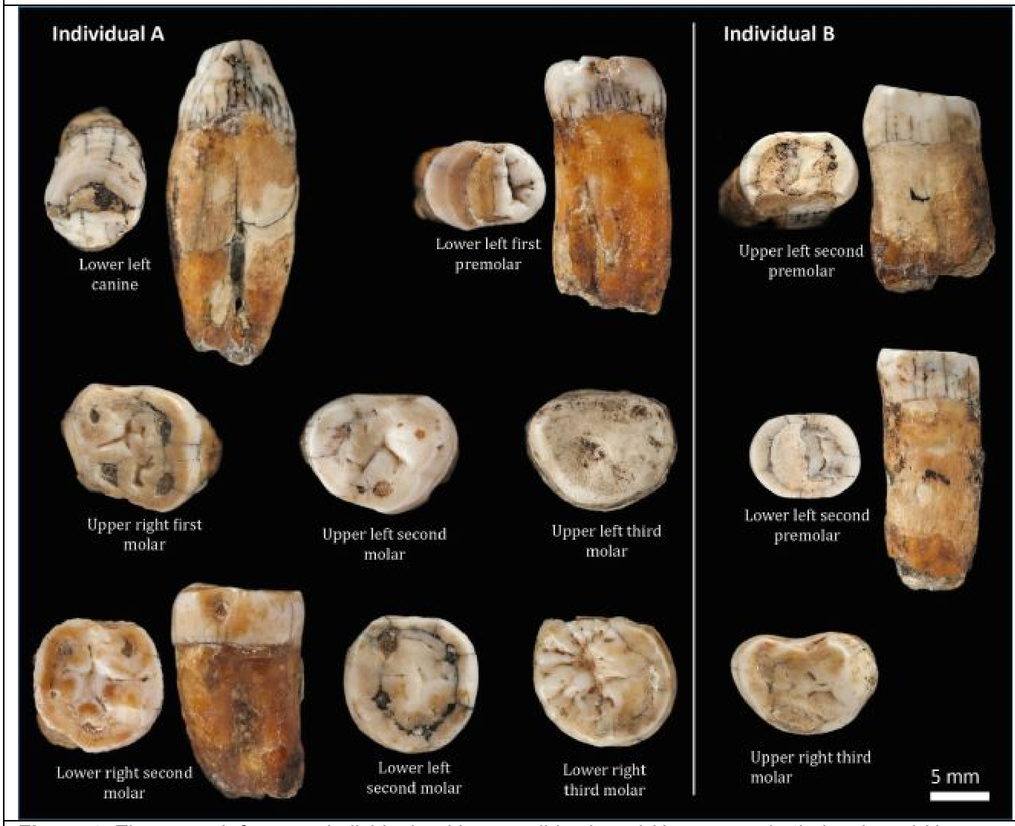
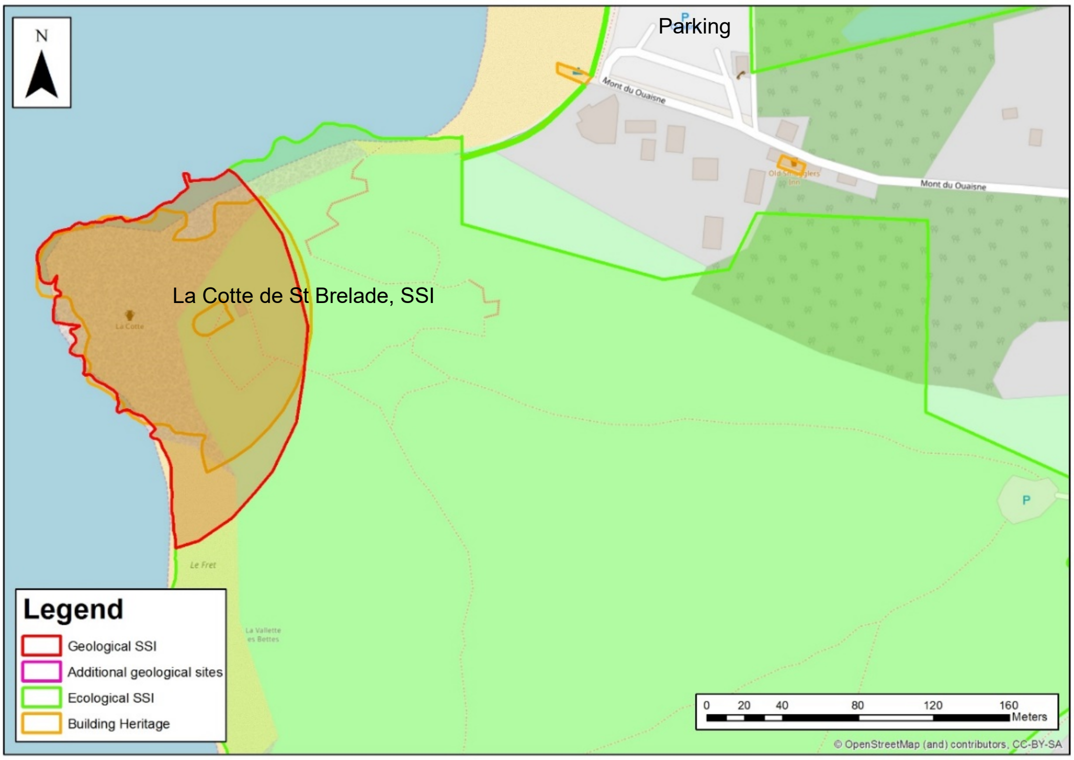


Figure 4: Eleven teeth from two individuals with a possible shared *Homo neanderthalensis* and *Homo sapiens* ancestry from last-cold-stage layers at La Cotte de St Brelade.

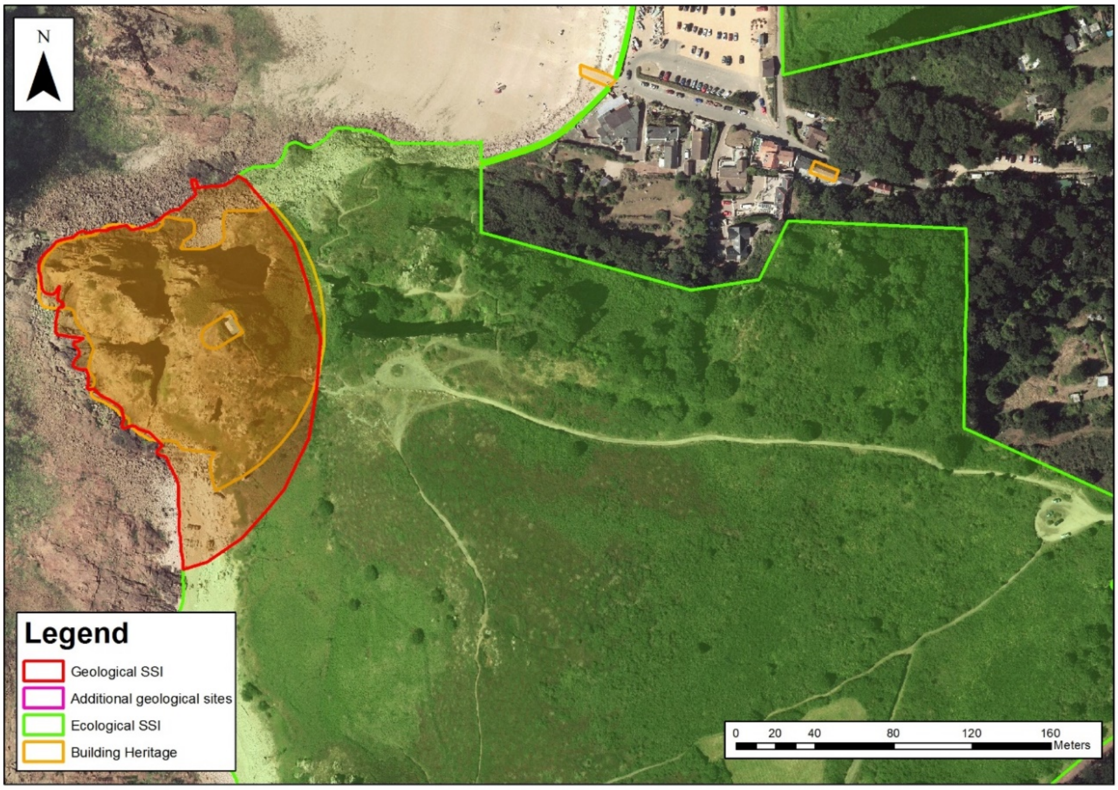
Photo 4: Excavations in the West Ravine in 2019. Part of ongoing research and site protection works funded by Jersey Heritage.

Map of the site boundary on a topographic base



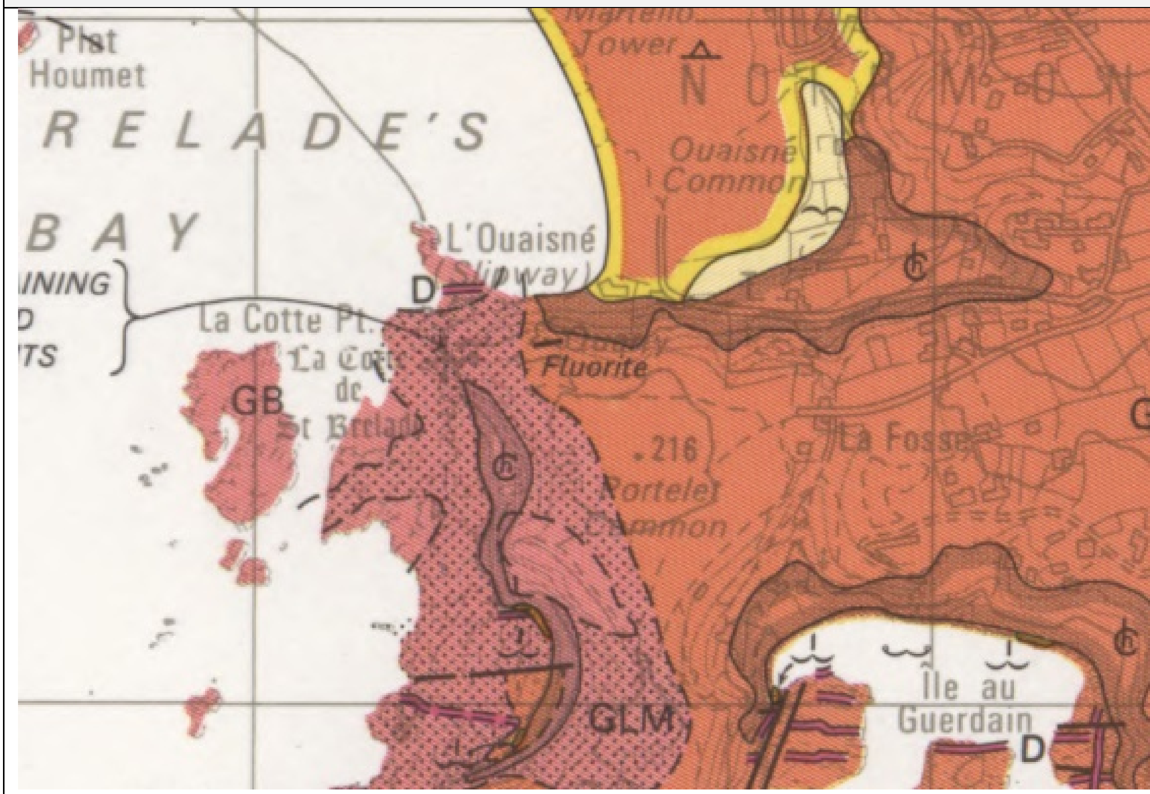
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

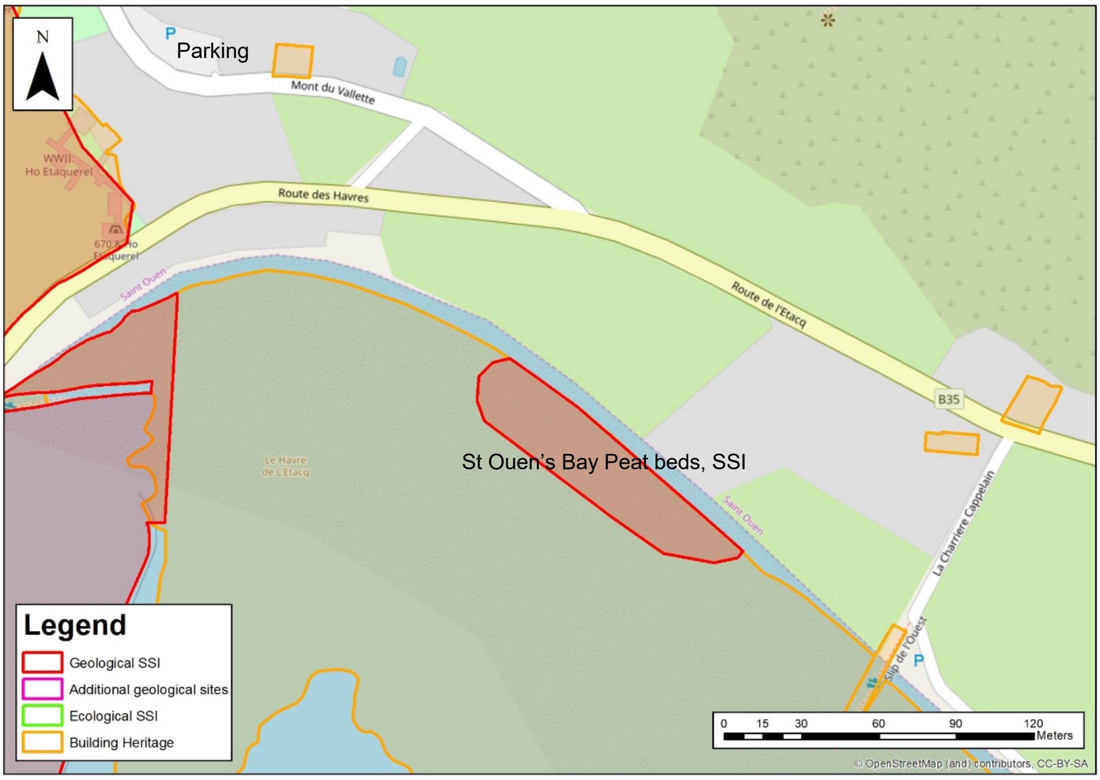


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

7.22 SITE NAME: ST OUEN'S BAY PEAT BEDS, SSI

Site Information:	
The St Ouen's Bay Peat Beds have been designated as an SSI because of the exposures of peat, which contain tree stumps, roots and tree branches. The site is principally of interest because the peat preserves fossil hoof prints, cattle bones, pottery and flint artefacts (Nichols and Blampied, 2016). The peat deposits are only infrequently exposed and are more often covered by beach sand. The peat was not exposed at the time of the BGS geodiversity audit.	
National Grid Reference: Mid-point: 31934, 71708 West end: 31888, 71737 East end: 31991, 71676	**Site Type:** Natural exposure
Site Ownership: To be confirmed	**Current Use:** Open country
Field Surveyors: None, site not visible during visit	**Current Geological Designations:** Geological SSI
Date Visited: None, site not visible during visit	**Other Designations:** Built Heritage, St Ouen's Peat Beds

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Site Description:
The following description is from the literature only, as the peat beds were not exposed at the time of the BGS site visit. Peat deposits are known from a number of sites across Jersey, where they are normally found in association with alluvium in river valleys or along the foreshore in many of the Island's bays. The largest expanse of coastal peat is infrequently exposed at St Ouen's Bay on the west coast, and it is thought that peat underlies the northern two thirds of the beach. The peat south of Kempt Tower is especially rich in bones and artefacts such as flints and pottery. Significant coastal deposits are also recorded from St Brelade's Bay and Les Échrehous reefs (Keen, 1981). **<u>Age of the Peat Deposits</u>** The upper surface of the peat deposits in St Ouen's Bay is dated to 3,984 ± 50 yr BP (SRR-437) and so deposition is likely to have started earlier than that date, perhaps 5,000 years before the present day. This is significantly younger than the oldest peat deposits known in Jersey, which are located at Quetivel Mill, where the base of the deposit yielded a boreal forest pollen assemblage with radiocarbon dates of 9,670 ± 70 years before the present (Bishop and Bisson, 1989).

Stratigraphy and Rock Types:	
Age: Quaternary	**Formation:** Peat
Rock Types: Peat	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	The closest parking is between L'Etacq and Le Pulec.
Safety of access	Safe access across the beach
Safety of exposure(s)	The exposures are safe to access but may be uneven underfoot.
Current condition	Unknown – not exposed at the time of the visit
Current conflicting activities	None
Restricting conditions	The peat beds are only periodically exposed. They are frequently covered by sand, and they are also covered by the sea at high tide.
Nature of exposure(s)	Beach foreshore

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological	Les Landes Area of Prehistoric Activity is an important prehistoric landscape with archaeological sites from the Palaeolithic, Mesolithic and Neolithic. It is of outstanding importance to the archaeological heritage of

and literary associations	Jersey and includes evidence of importance to European prehistory (HER Number 0900175; Listed place OU175). Strongpoint L'Etacquerel is part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall. It is a significant structure with a unique tunnel system to the rear (HER Number 0900041; Listed building OU0041 and OU0042). St Ouen's Bay Area of Peat Deposits (HER Number 0900227; Listed place OU0227). South View is a mid-18th-century house (HER Number 0900114; Listed building OU0114). La Porte is an early-18th-century farmstead (HER Number 0900112; Listed building OU0112). Sans Ennui is a late-17th-century house and coastal farm group (HER Number 0900113; Listed building OU113). La Maison de l'Etacq is a farmstead with 18th-century origins (HER Number 0900253; Listed building OU253). L'Anciennete is a 17th-century house (HER Number 0900245; Listed building OU245). There are several resistance nests, which are part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall: Thiebaud (HER Number 0900184; Listed building OU0184), Lewis's Tower (HER Number 0900158; Listed building OU0158), La Crabiere (HER Number 0900033; Listed building OU0033), Kempt Tower (HER Number 0900157; Listed building OU0157), La Mare Mill (HER Number 0900187; Listed building OU0176, OU0187), Dune (HER Number 0100234; Listed building BR0234), La Carriere (HER Number 0100262; Listed building BR0262), La Pulente (HER Number 0100264; Listed building BR0264), Steps Punkt 43 (HER Number 1000171; Listed building PE0171) and High Tower (HER Number 1000169; Listed building PE0169). Les Corvees is an 18th-century farmstead (HER Number 0900025; Listed building OU0025). Lewis's Tower was built in 1835 (HER Number 0900092; Listed building OU0092). Barge Aground is a 1930s beach chalet (HER Number 0900160; Listed building OU0160). Kempt Tower was built between 1831 and 1837 (HER Number 0900085; Listed building OU0085). Lake Vale is a farm group with 17th-century origins (HER Number 0900264; Listed building OU0264). The Coastal Artillery Battalion Command and Observation Post was part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall. It was the headquarters for the 1st Battalion 1265 (HER Number 0900118; Listed building OU0118). Homestead is a farmstead with 17th-century origins (HER Number 0900076; Listed building OU0076). The Organisation Todt Railway Bridge, built in 1942, is part of an integrated network of German structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall. It is one of the only Organisation Todt railway structures left in Jersey (HER Number 1000203; Listed building PE0203). Abreuvoir was built in 1887. It was part of a collection of Island-wide historic roadside structures designed for the provision of the public water supply (HER Number 1000193; Listed building PE0193). Les Malzards Farm is a late-18th-century farmstead (HER Number 1000194; Listed building PE0194). Clos Luce is an 18th-century cottage (HER Number 1000214; Listed building PE214). La Maison du Sud is a 17th-century cottage (HER Number 1000091; Listed building PE0091). La Piece Michel is a farmstead with 17th-century origins (HER Number 1000229; Listed building PE0229). Elm Farm is an 18th-century farmstead (HER Number 1000228; Listed building OU0228). Bethel House is an 18th-century house (HER Number 1000226; Listed building PE0226). A Gallo-Roman artefact scatter (HER Number 1000269; AAP PE0269). Alexandre Farm is an 18th/19th-century farmstead (HER Number 1000273; Listed building PE0273). Les

	Blanches Banques is a prehistoric landscape from the final Neolithic to the early Bronze Age. It includes the following sites: La Tete des Quennevais, The Great Menhir, The Little Menhir, The Ossuary and The Broken Menhir (HER Number 0100228; Listed place BR0228). Site of a World War I prisoner-of-war camp (HER Number 0100193; Listed place BR0228). La Pulente artefact scatter (HER Number 0100363; Listed place BR0363). La Rocco Tower was built between 1796 and 1801 (HER Number 0100089; Listed building BR0089). Simon Sand & Gravel finds (HER Number 1000325).
Aesthetic landscape	Not applicable
History of Earth science	Not known
Economic geology	None

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology	Regional	Good	Descriptions	X

Geoscientific Value of the Site

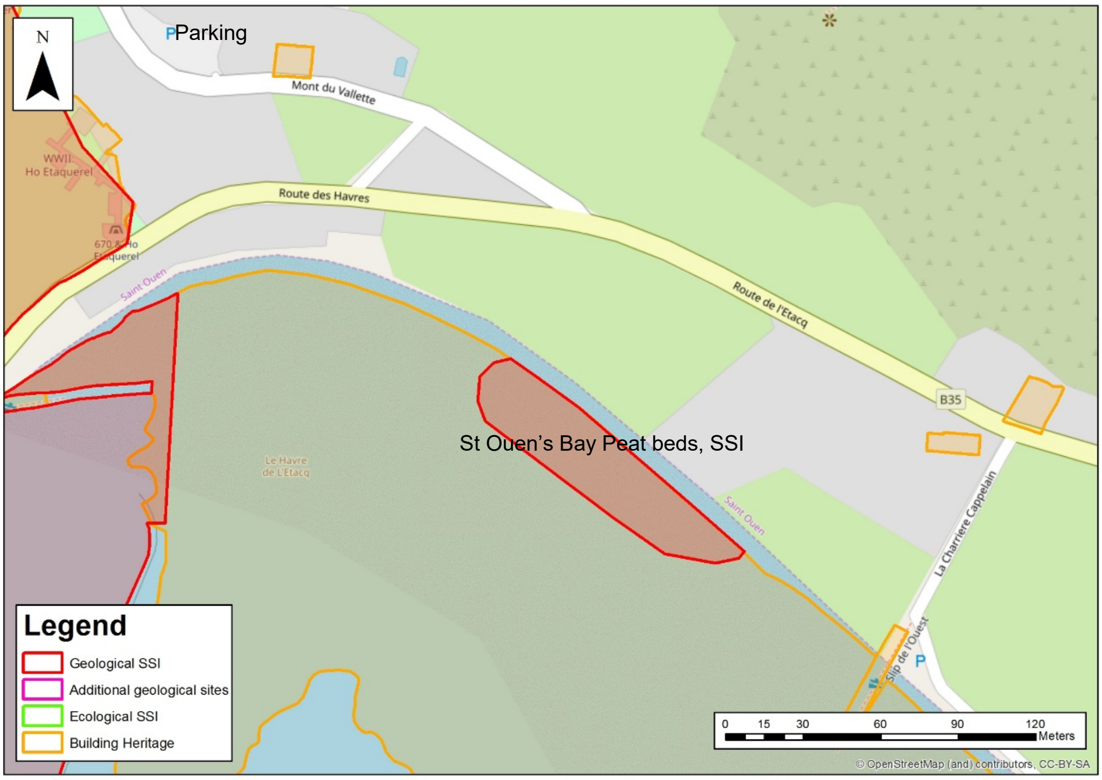
The principal features of interest in this site are the peat beds, which are infrequently exposed, normally after storms. It is important that this site is protected, as it has the potential to contain prehistoric remains. It is also an excellent teaching site, as it is easily accessible.

Assessment of Site: Current Site Usage	
Community	Used for tourism and leisure activities
Education	This site is mentioned in local geology guides, so it is probably visited by groups and researchers interested in geology.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	This site is fragile and susceptible to collectors, who could damage the site.
Potential use	This is a good site to use to describe the effects of climate change and prehistoric archaeology.

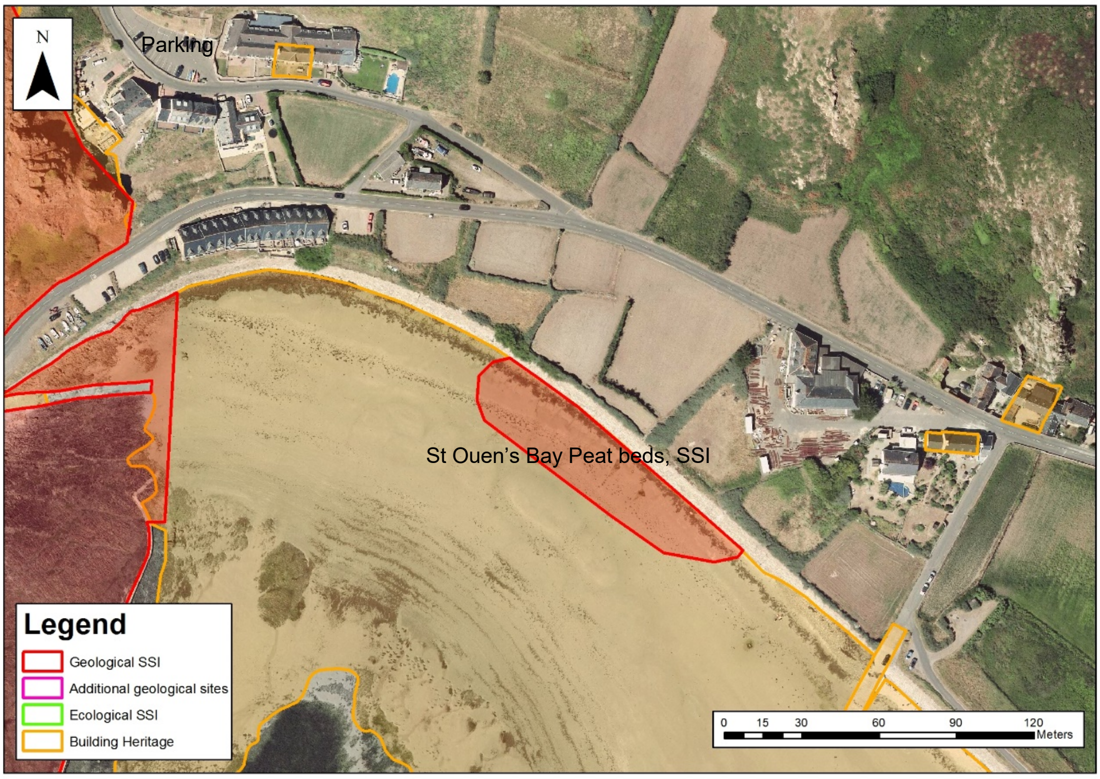
Site Photos:
The peat deposits were not exposed during our visit. Please see the Jersey Geology trail website for many good images of the peats exposed after storms. http://www.jerseygeologytrail.net/Superficial_Deposits.shtml

Map of the site boundary on a topographic base



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

8 Proposed Additional SSI Site Reports

8.1 SITE NAME: ST PETER'S VALLEY, PROPOSED SSI

Site Information:	
Within St Peter's Valley, between Quetivel Mill and Gargate Mill, there are a number of small quarries and road cuttings in the *Jersey Shale Formation*. Closer to Quetivel Mill, the rocks contain a range of internal structures that indicate that this formation was deposited within the middle parts of a submarine fan. In a small trackside cutting behind Gargate Mill, a conglomerate can be seen; it is interpreted as having been deposited in canyons or the inner parts of the submarine fan. **The two quarries described in this report must not be visited without the permission of the landlords. The roadside outcrops are along an extremely busy road, so care must be taken when visiting them.**	
National Grid Reference: Mid-point: 37467.082, 68679.511 West end: 37363.657, 68901.5 East end: 38239.887, 68186.992	**Site Type:** Artificial section and artificial quarry works
Site Ownership: To be confirmed	**Current Use:** Domestic land and urban
Field Surveyors: RS Kendall and S Arkley	**Current Geological Designations:** None
Date Visited: 18 October 2019	**Other Known Designations:** None
Site Map	

Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Latest Precambrian (Precambrian)	**Formation:** *Jersey Shale Formation*
Rock Types: Sandstone, siltstone and claystone with rare intra-formational conglomerates	

Site Description:

Introduction

This site is an amalgamation of a number of small road cuttings and disused quarries in St Peter's Valley that provide an opportunity to examine the middle fan deposits of an ancient submarine fan. Also exposed in this valley, further north, are sediments that are thought to have accumulated in a canyon or the inner part of the submarine fan. All these rocks are part of the *Jersey Shale Formation*, which was deposited in a submarine fan on an Andean-type continental margin (a similar geological setting to the Andes area today); this fan formed roughly 600 million years ago, just before the Cadomian Orogeny, and it was folded and weakly metamorphosed during this orogenic event (Helm and Pickering, 1985; Bishop and Bisson, 1989). Other parts of the fan can be seen in exposures at Grand Étacquerel, Petit Étacquerel and Mont Huelin Quarry.

Bedrock Units

Jersey Shale Formation

Turbidites are sedimentary deposits that are genetically related to subaqueous sediment gravity flows in which fluid turbulence is the principal particle support mechanism (also known as turbidity currents). A turbidity current is generated as a result of the contrast between the density of the flow entering the basin (water-sediment mix) and the density of the water within the receiving basin. Turbidity currents can be triggered by earthquakes and storms or may simply be related to variable fluvial input into bodies of water during climatic fluctuations on land or changes in the relative sea level (marine or even deep lacustrine). They often form as a series of subaqueous fan systems on the basin floor. A detailed study of the *Jersey Shale Formation* was made by Helm and Pickering (1985), who identified six sedimentary facies, which they grouped into four facies associations. These associations represent deposition in different regions within the submarine fan: I – canyon or inner fan channel fill, II – middle fan channel fill, III – lower fan / outer fan deposits and IV – outer fan deposits.

The *Jersey Shale Formation* is estimated to be 2,500 m thick; it contains the oldest rocks exposed in Jersey. They mainly comprise of cycles of mudstones, siltstones, sandstones and minor conglomerates, which have subsequently undergone low-grade regional metamorphism and have been affected by tectonic processes (Bishop and Bisson, 1989).

The lithologies and sedimentary structures seen in the rocks exposed in the lower part of St Peter's Valley (Localities 1–3) indicate that they were deposited in the middle parts of the submarine fan. The rocks here are characterised by high sand/shale ratios of about 90/10. The beds amalgamate, and split or assume a lens-like shape, while the bed bases are commonly scour, down-cutting into the beds below (Association II, Helm and Pickering, 1985). Rocks of this type are only found in this area and so it is thought that they form a lenticular body that is graded or cuts laterally into other parts of the fan (and other facies associations).

At Locality 4, behind the mill at Gargate, there is a cutting in the side of a lane that provides a rare opportunity to examine the coarsest element of the *Jersey Shale Formation*. These rocks are part of Facies Association I of Helm and Pickering (1985), and they dominantly comprise conglomerates, which occur in isolated exposures along the southern margin of the *North-west igneous complex*. The conglomerates are clast supported and pebble-to-cobble grade. The clasts are sub-rounded to rounded and are derived from sedimentary rocks (intra-formational) and intrusive, acid and intermediate, volcanic, medium-to-high-grade metamorphic and minor basic volcanic fragments (Helm and Pickering, 1985). This lithologically diverse assemblage of clasts suggests that the source area for the *Jersey Shale Formation* at this time was also mixed. These sediments are interpreted to have been deposited in canyons or in the inner parts of the submarine fan. Other locations where the conglomerates can be examined, although the exposures are poor, are La Ville es Viberts, St Anastase and Carrefour Selous (Bishop and Bisson, 1989).

Structures

During the Cadomian Orogeny, the *Jersey Shale Formation* was folded and weakly metamorphosed. Helm (1983, 1984) describes two main phases of deformation that are observed in the *Jersey Shale Formation*. There are early folds (D_1), which are simple, singly plunging folds or doubly plunging periclines, with axes that typically trend from WNW–ESE through N–S to NE–SW. Helm thought that the more complex periclines probably represented early-forming non-cylindrical buckles associated with variations in lithology. Helm also identified D_2 axial planar fabrics and faults associated with major folds and noted that both D_1 and D_2 folds are overprinted by a system of late, radial fractures, which he attributed to the vertical stress associated with the rising basaltic magma that infills some of the fractures. He also thought that the occurrence of closely spaced N–S joints might indicate yet another, fourth deformation and noted that a similar fabric exists in the adjacent North-west granite complex. Much of the evidence for folding in the *Jersey Shale Formation* can be found across St Ouen's Bay and can be examined on the foreshore at Petit Étacquerel and the area to the south. However, some of the evidence for the types and orientations of the folding is based on the analysis of cleavage patterns, which are well developed, especially at Locality 3 (see map), where cleavage can be seen especially well in the finer-grained lithologies within the *Jersey Shale Formation*.

Age and regional correlation

Miller *et al.* (2001) produced a uranium-lead isotope date for the *Jersey Shale Formation*. The youngest zircons yielded nearly concordant dates of 586.7 ± 3.0 Ma and 587.1 ± 2.7 Ma, providing a maximum depositional age for the unit. They also tested zircons from the overlying volcanic rocks (Anne Port Rhyolite), which had an upper intercept date of 582.8 +3/-2.7 Ma; this is considered to be the date of eruption. These dates provide good constraints on the age of the *Jersey Shale Formation*.

The *Jersey Shale Formation* has been correlated with the Upper Brioverian rocks of Baie de St Brieuc and the Manche regions of France on the basis of lithological studies (e.g., Graindor, 1957; Dupret *et al*., 1990; Guerrot *et al*., 1989). The Brioverian, in France, is divided into upper and lower sequences, with the Coutances quartz diorite used as a regional time marker (584 ± 4 Ma; Guerrot *et al*., 1989) because it intrudes and metamorphoses the older sequence but not the younger. However, Miller *et al.* (2001) have produced a minimum date for the formation that indicates that it was deposited in or after *c.* 587 Ma, which may suggest that the *Jersey Shale Formation* should be placed in the Lower Brioverian. Alternatively, it may be that the deposition and deformation of the Brioverian volcano-sedimentary sequence was diachronous, which would mean that these lithological and age relationships cannot be applied across the whole region (Miller *et al*., 2001).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	All of the locations that make up this site are close to the main road that runs through St Peter's Valley. However, parking is limited to small, dedicated car parks along the side of the road and one National Trust for Jersey-owned site.

Safety of access	These sites require extreme caution to visit. The road cuttings around Locality 2 are along a very busy road. It is recommended that if these sites are visited, there should always be someone dedicated to looking out for traffic.
Safety of exposure(s)	The quarries at Localities 1 and 3 have high faces, so they should be viewed from a suitable distance.
Access	Localities 1 and 3 are on private land. Permission must be obtained before visiting these localities.
Current condition	Most of the outcrops are in good condition but should be periodically cleared of vegetation to ensure that the features of interest continue to be visible.
Current conflicting activities	None
Restricting conditions	Permission must be obtained before visiting sites on private land. Traffic is an issue at some of these sites.
Nature of exposure(s)	Track and roadside cuttings and disused quarries

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Locality 4: Gargate Mill and house is a rare surviving example of a former watermill built *c.* 1830 (HER Number 1000064; Listed building PE0064). La Hague Manor / St George's School is an important manor house; the core of the house was built starting in 1753 (HER Number 1000079; Listed building PE0079). Hamptonne is a farmstead with an 18th-century house with late-16th-century fabric (HER Number 1000031; Listed building PE0031). Localities 1, 2 and 3: Le Becquet is a late-19th-century house with some 17th-century fabric (HER Number 0600186; Listed building LA0186). Le Moulin de Quetivel is an 18th-century mill, a rare survivor of its type and the last remaining working watermill on the island (HER Number 1000045; Listed building PE0045).
Aesthetic landscape	None
History of Earth science	Not known
Economic geology	None

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology	Regional	Good	Detailed studies	X
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site
These outcrops in St Peter’s Valley are of importance for geoconservation, as they are the only places where the middle (Facies Association II, Helm and Pickering, 1985) parts of the *Jersey Shale Formation* submarine fan can be examined. The small outcrop of conglomerate at Gargate Mill is similarly rare and provides an opportunity to examine the coarsest units within the fan; these units were deposited in proximal canyons within the fan (Facies Association I, Helm and Pickering, 1985). Along with other sites in this formation at Grand Étacquerel, this site provides the opportunity to contrast the different styles of sedimentation in different parts of the fan.

Assessment of Site: Current Site Usage	
Community	These sites are currently in use as verges, gardens and waste ground.
Education	These localities are mentioned in geological guides for Jersey, so they are likely visited by people interested in geology.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust.
Potential use	The sites that are not near busy roads could be part of a geotrail or used for school trips and higher education and research.

Site Photos:

Photo 1: View of a road cutting between Localities 2 and 3 on the east side of the road. Examples of high-sand/shale-ratio sandstones with bed bases that downcut into the beds below are visible. BGS © UKRI 2020.

Photo 2: View of a road cutting at Locality 2 on the east side of the road. Visible here are sediments typical of Helm and Pickering's (1985) Facies Association II, with their characteristic common sandstone beds. BGS © UKRI 2020.

Photo 3: At Locality 2, in the finer-grained units that are exposed here, cm-scale beds of very fine, glassy, greenish rocks can be seen interbedded with the mudstones and sandstones. These are thought to be tuffaceous layers – they contain volcanic ash. BGS © UKRI 2020.

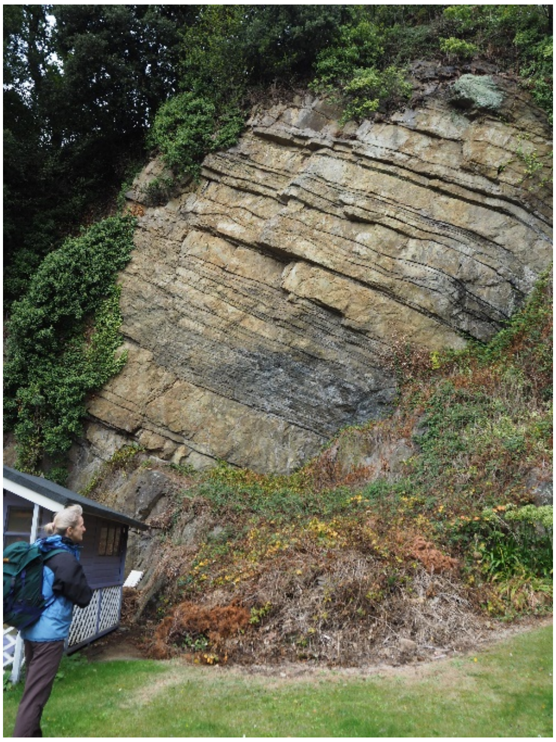
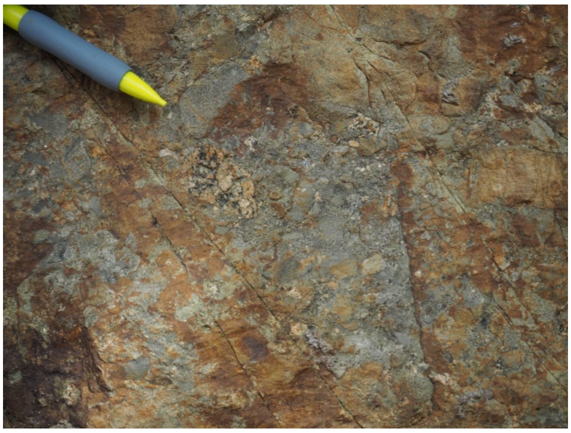


Photo 4: General view of Locality 3, a disused quarry in a private garden on the east side of the valley. Note the high proportion of thick sandstone beds, typical of Facies Association II, and the erosive bases of some of the beds. BGS © UKRI 2020.

Photo 5: Detailed image from Locality 3. This picture illustrates a cleavage set developed in the finer-grained mudstones. Features like this were used by Helm (1983) to reconstruct folds in the *Jersey Shale Formation*. Pencil for scale. BGS © UKRI 2020.

Photo 6: General view of Locality 4, showing an outcrop of Helm and Pickering's (1985) Facies Association I. The outcrop is on the east side of the track behind Gargate Mill. BGS © UKRI 2020.



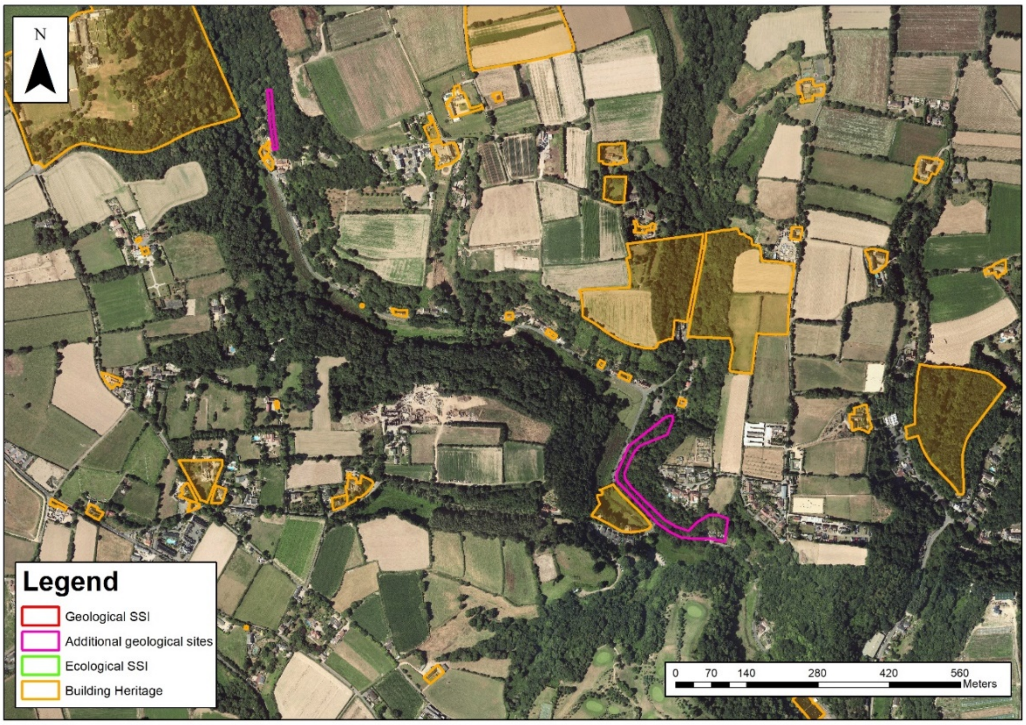
Photos 7 (left) and 8 (right): Detailed views of the outcrop at Locality 4, illustrating details of the clasts visible in the conglomerate. The clasts are sub-rounded to rounded and are derived from sedimentary rocks (intra-formational) and intrusive, acid and intermediate, volcanic, medium-to-high-grade metamorphic and minor basic volcanic fragments. BGS © UKRI 2020.

Photo 9: This photo was taken facing south from the 'Victoria in the Valley' pub. Here, St Peter's Valley is broad and flat-bottomed with an apparent misfit stream. BGS © UKRI 2020.

Map of the site boundary on a topographic base

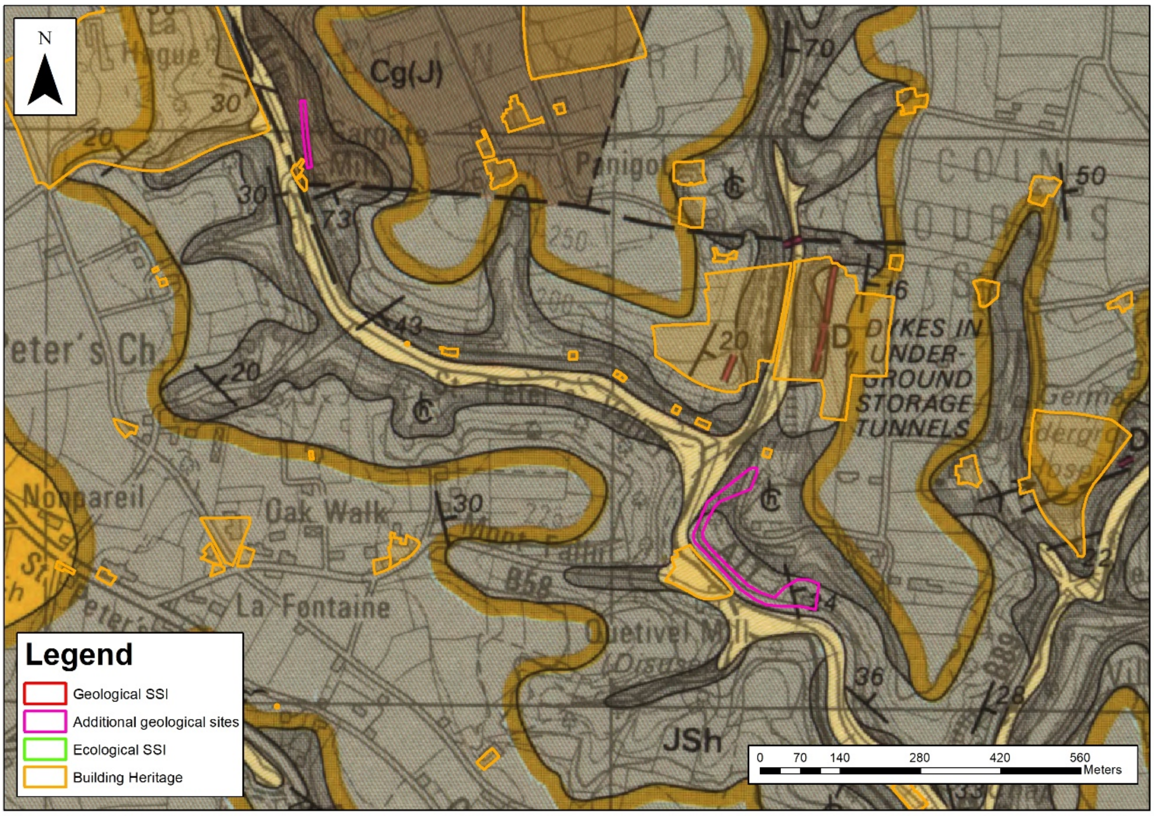
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Google, Map data ©2020.

Map of the site boundary on a published geological map

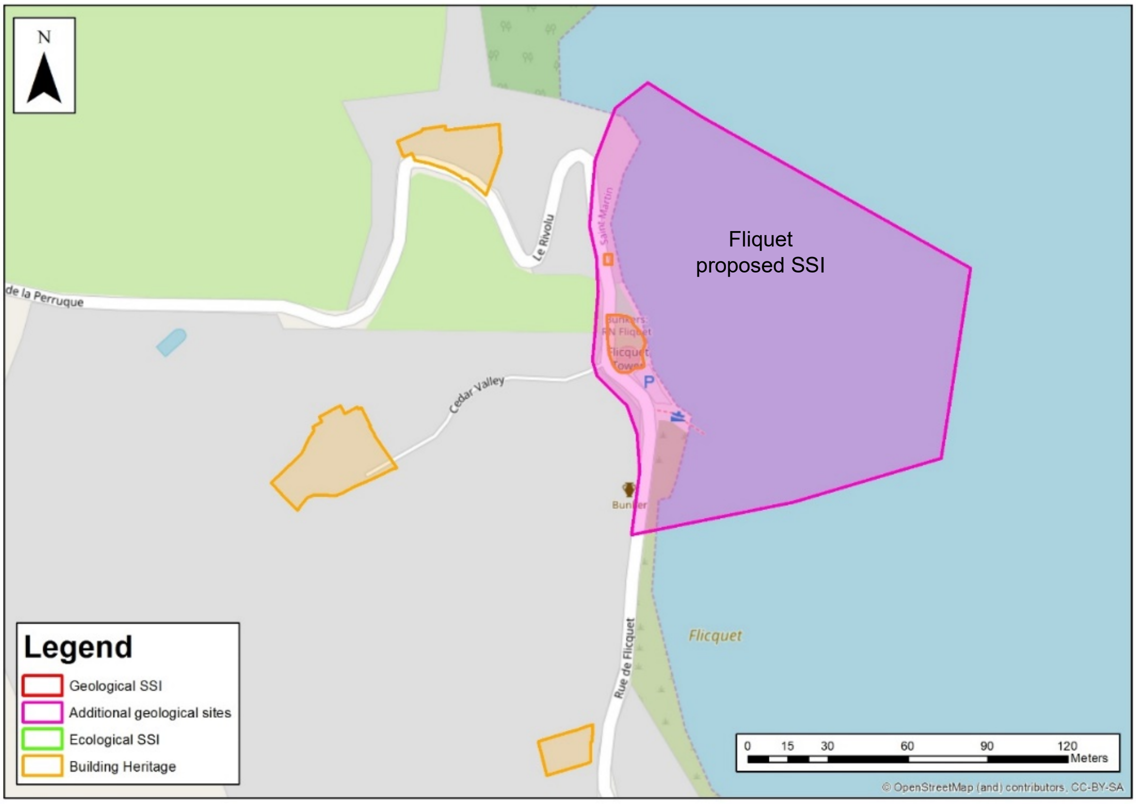


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

8.2 SITE NAME FLIQUET, PROPOSED SSI

Site Information: Fliquet is a coastal site located in the north-east corner of Jersey that contains the only known peat beds on the Island that have been dated to more than 25,000 years ago. The bed of compressed peat infills a shallow elongated basin cut into the *Rozel Conglomerate Formation* and generally lies preserved beneath the present-day pebble beach, although it is occasionally exposed by storms. Good intertidal exposures of typical *Rozel Conglomerate Formation* rocks are also present at the site, along with a beach cliff displaying Quaternary head deposits.	
National Grid Reference: Mid-point: 48108, 70355 North end: 48068, 70442 South end: 48061, 70272	**Site Type:** Natural section/exposure and sub-surface deposit
Site Ownership: To be confirmed	**Current Use:** Open country, coastal
Field Surveyors: S Arkley and C Auton	**Current Geological Designations:** None
Date Visited: 15 October 2019	**Other Known Designations:** Fliquet Tower (Folio No MN0190) and Telegraph Cable Hut (MN0193) both lie within the proposed site. Areas above the HWM are within Jersey National Park.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Site Description:

Introduction

Fliquet comprises a coastal site on the foreshore above the low-water mark, just below the stone seawall constructed at the head of the bay. The site is important because it contains a bed of compressed peat infilling a shallow elongate basin cut into the *Rozel Conglomerate Formation*. The extent of the peat, which is preserved beneath the present-day pebble beach, was established by a series of auger traverses (Coope *et al*., 1980, 1993, figure 3.1) across the foreshore. The peat, which has been C14 dated to >25.5 ka BP, is thought to have formed under Arctic to Boreal climatic conditions during the Early Devensian, *c.* 110–120 ka BP (OIS 5a–d), prior to the formation of the '8 m Ipswichian' raised beaches (*c.* 121 ka BP; OIS 5e). The peat is reported to reach 0.6 m in thickness adjacent to the sea wall. It is only exposed sporadically, typically after storm events strip the modern beach cover.

Bedrock Units

Rozel Conglomerate Formation

The *Rozel Conglomerate Formation* is well exposed on the wave-cut platform and in the low outcrops that surround the concealed peat basin at Fliquet. The wave-washed surfaces show typical facies of the conglomerate, typified by well-rounded to sub-rounded pebbles and cobbles composed of volcanic extrusive rocks, *Jersey Shale Formation* rocks and, less commonly, very well-rounded cobbles of more exotic acid, plutonic igneous rocks. The deposit is clast-supported with a siltstone matrix. Small discontinuous channels, infilled with maroon sandstone, are present locally.

Quaternary Deposits

Fliquet Boreal and Arctic peat bed

The Fliquet peat and Arctic mud were not visible at the time of the visit, but the form of the subcrop, mapped in detail by Coope *et al*. (1980, 1993) relative to their mapped foreshore exposures of the *Rozel Conglomerate Formation*, indicates that the peat infills a shallow narrow basin. Cross-sections drawn from test pits sunk by Coope *et al*. (1980, 1993) indicate that the areal extent of the organic sediments is *c.* 20 m x 20 m. These organic sediments have been variously described as 'compacted peat deposits of the Fliquet Arctic Bed' by Bishop *et al*. (2003, p. 6) and as 'gravelly peat' with flattened pebbles and wood fragments (Bishop *et al*., 2003, p. 20). They are simply shown as 'peat' on the published geological map and associated cross-sections, but they are described as 'clayey peat' overlying 'silt' in the vertical geological section drawn for the pollen spectrum of the site by RL Jones (figure 3.3, Coope *et al*., 1993). The top of the peat was at *c.* 6.4 m above the mean sea level in 1978; its base is at *c.* 5.8 m above the mean sea level.

An analysis of fossil pollen and coleoptera (beetles) from the peat indicates that the base of the deposit formed in a climate that allowed woodlands dominated by pine and birch to develop close to the sea. However, most of the peat accumulated in a more severe climate, leading to less tree cover and more open ground. The fragmentary insect fossils are said to be visible with a hand lens, but the pollen requires microscopic analysis. Wood fragments are visible in hand specimens, but no plant macrofossil analysis appears to have been undertaken at the site. A C14 date was obtained from twigs collected from the peat close to the North-west margin of the outcrop. However, this was not the sample locality close to the seawall that was subjected to palynological and coleopteran analysis. Consequently, there is no direct indication of the position of the C14 dated level with respect to the pollen and beetle-derived biostratigraphy of the site.

The organic deposits occur at a lower elevation than the head exposed in the nearby cliffs. The compressed nature of the siltstone clasts and wood fragments within the lower part of the peat has been taken to indicate that the deposits were buried beneath a significant thickness of cold and warm stage (Devensian and Holocene) head deposits. Coope *et al.* (1980) note that up to 10 m of 'rubble head' are present in the cliff sections immediately adjacent to the peat outcrop. Nowhere is a contact between the head and peat exposed, although the postulated contact between these layers is obscured by the sea wall (as it was during the studies in the 1970–80s).

Coope *et al*. (1980) reported that storms in 1977–78 removed much of the pebbly beach that now conceals the peat, revealing that the peat outcrop extended beneath the sea wall. During the site visit for this report, gravelly head was seen to extend behind the sea wall at its northern end for at least a short distance, supporting the interpretation that the peat is overlain by head deposits inland of the sea wall. This also supports the inference that the peat on the foreshore was compressed beneath a thick sequence of Devensian and later sediments, which have been subsequently removed by Holocene marine erosion.

Head

Head deposits are exposed at the base of vegetation-covered sea cliffs immediately adjacent to the telegraph tower. Up to 2.5 m of silty head is visible resting directly on the *Rozel Conglomerate Formation* and it was seen to extend behind the sea wall. It is unclear whether the head and the peat, exposed on the foreshore, extend inland to within the valley of the small stream that drains eastwards to the beach. The head is predominantly silty and well-bedded, with a bed of more gravelly sediment, up to 25 cm thick, directly overlying the conglomerate. Three pebbly units are exposed, with two intervening loessic units (typically 30–50 cm thick). The basal gravelly unit is clast-supported and poorly sorted and contains angular cobbles of conglomerate up to 10 cm in diameter. The two higher gravelly units are well-sorted, matrix-rich gravels with subangular pebbles that are typically 2–5 cm in diameter. All of the beds show diffuse, irregular bases indicative of channelled, erosional contacts, suggesting deposition as colluvium (slope deposits) with a degree of water sorting and the reworking of wind-blown loess, debris flows and talus. Consequently, these sediments appear to represent a category of loessic head.

Potential for Future Scientific Interest

Although the peat bed at Fliquet is rarely exposed, its preservation beneath the present-day beach deposits makes it an important site for possible further specialist scientific research. The previously published detailed studies of the pollen and fossil insect remains by Coope *et al*. (1980) suggest that they provide evidence of an Arctic to Boreal climate in Jersey during IOS stages 5a–d. This is during a period of cold interstadial climatic conditions, immediately predating the sea level rise during the warm (Ipswichian warm stage) period, which is represented by the deposition of the 8 m raised beaches (IOS stage 5e). The IOS stage 5a–d age is currently inferred from the biostratigraphy, but it is only constrained by a single >25.5 ka BP C14 date from close to the base of the peat unit.

Modern AMS C14 dating of plant remains from the Fliquet Bay deposits has the potential to extend the age to >*c.* 50 ka BP, and the U-series dating of peat has the potential to provide a finite age in the range of up to 100–200 ka BP. Because the dating of smaller samples is now possible, sequential sampling through the complete organic sequence is possible, allowing an estimation of the rate of the changes in the climate and environment through time to be established. However, because of the difficulty in sampling the organic deposits, which lie close to the water table and (except in exceptional circumstances) beneath present-day pebbly beach deposits of variable thickness, this would probably involve the mechanical excavation of temporary shuttered test pits, rather than simple coring or augering. It would therefore need to be a well-resourced research task.

The ease of access to the site also makes it a good place for a less rigorous examination of examples of loessic head and the *Rozel Conglomerate Formation*. Both are readily accessible to anyone interested in these aspects of Jersey's geological history.

Other Sites and Regional Correlations

The Fliquet Bay site is one of three sites in Jersey where pre-Holocene organic-rich sediments have been recorded. Peats overlying organic mud resting on a wave-worn surface cut in Jersey shale were exposed from beneath the modern storm beach at St Aubin's Bay (Belcroute) during storms in 1981 (Coope *et al*., 1985, 1986, 1993). The organic deposits at St Aubin's Bay and the Fliquet Bay sediments have several similarities. The peat and mud at St Aubin's Bay contain angular and rounded clasts of shale, suggesting that both are detrital deposits (analogous to head with a matrix of organic sediment). Both of the St Aubin's Bay sediments are described as 'compacted' and have yielded a pollen spectrum and fossil coleopteran (beetle) assemblage that indicates deposition under tundra (Arctic) conditions. The St Aubin's Bay deposits are undated, but their flora and fauna suggest that they were formed during a cold stage, during the Early Devensian (during IOS stages 5a–d) or earlier.

Both the Fliquet Bay and St Aubin's Bay organic sequences have been compared with similar sequences from Omonville-la-Rougue, Ecalgrain, Herquemoulin, Petit Beaumont and Vauville on the Cherbourg Peninsula in Normandy (Coope *et al*., 1987). All sites in Jersey and Normandy provide evidence of a similar pattern of the climate, vegetation and relative sea-level changes that occurred in the region during the Early Devensian (Early Weichselian) to late Ipswichian (late Eemian; OIS stages 5a–6). Coope *et al*. (1986) suggest that all the sites record a single phase of climatic deterioration and that the relative sea level fell at this time.

Pre-Holocene deposits of organic silt and sand, intercalated with head containing clasts of granitic and volcanic rocks, were exposed in an excavation for the construction of Queen's Valley Reservoir (Jones *et al*., 2004). The sediments yielded pollen, plant macrofossils and coleopteran remains, indicating that the organic sediments were deposited under periglacial conditions. The plant remains were C14 dated to 10,490–10,720 C14 yr BP (*c.* 12020–12,520 years ago). This shows that the organic sediments were laid down during the early part of the Loch Lomond (Younger Dryas) Stadial and are thus much younger than those recorded from the Fliquet and St Aubin's bays. The Queen's Valley Reservoir organic sediments, however, provide the only dated sequence of pre-Holocene organic sediments in Jersey. They provide unique evidence of the environmental conditions, vegetation and climate on the Island during the Devensian late cold stage.

Stratigraphy and Rock Types:	
Age: Upper Cambrian to Ordovician	**Formation:** *Rozel Conglomerate Formation*
Rock Types: Coarse conglomerate with subordinate sandstone and mudstone	
Age: Quaternary	**Formation:** Head
Rock Types: Bedded silt with gravel layers	
Age: Quaternary	**Formation:** Peat
Rock Types: Peat	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	A small car park (accommodating 6–8 cars) is located at the site between the road and the seawall, next to Fliquet Tower. The site can be viewed from the car park.
Access to the site	There is open access onto the beach/foreshore via a well-constructed slipway. The peat bed is generally covered by beach deposits and not accessible. Most of the bedrock exposures are in the intertidal zone and will usually be covered at high tide. The cliff section at the back of the beach, which exposes the Quaternary deposits, lies above the high-tide mark and should generally be accessible.
Safety of access	There is safe access to the foreshore. However, all visitors should be aware of the tide times and access routes when planning a visit.
Safety of exposure(s)	Reasonably safe. The small cliffs exposing the head deposits at the back of the beach appear to be generally stable, but care should always be taken beneath cliffs, particularly in any overhanging areas. The bedrock exposures have an uneven, water-worn surface and are often slippery with algae and seaweed.
Current condition	Many rock exposures are clean and free of vegetation. However, in the intertidal zone, the rocks may be covered by barnacles, algae and seaweed.
Current conflicting activities	None known
Restricting conditions	The peat beds are generally covered by beach deposits (sand and gravel) and rarely exposed. The bedrock exposures are dominantly in the intertidal zone and therefore covered at high tide. Quaternary sections have no known restrictions, as they lie above the normal high-tide mark.
Nature of exposure(s)	Intertidal and backshore bedrock exposures, plus small Quaternary cliff sections

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Fliquet Tower is a Conway tower built *c.* 1794 (HER Number 0700190; Listed building MN0190). The tower is thought to have been constructed in the 1780s to guard the east coast, which was considered susceptible to attack from France. Originally built as a round tower with a typically Jersey design, it was substantially altered at some point, with the top floor and mâchicoulis removed, reducing the height of the tower. During the occupation, the Germans modified the area, including the tower. Telegraph Cable Hut was built in 1870 (HER Number 0700193; Listed building MN0193). Cedar Valley is a picturesque Victorian villa built in 1880 (HER Number 0700188; Listed building MN0188). Fliquet Castle is a 20th-century house and cottage (HER Number 0700195).
Aesthetic landscape	Coastal. Located on the far north-eastern corner of Jersey, the sheltered bay has panoramic views and is quiet and unspoilt. It is reportedly possible to see France on a clear day. No litter was seen.
History of Earth science	No known association
Economic geology	No known association

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology	Educational	Good	No data	
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology	Regional	Good	Detailed studies	X

Geoscientific Value of the Site
The uniqueness of this site lies in the peat beds, which have been dated to more than 25,000 years ago and lie protected beneath the present-day beach deposits. These beds have great potential, with more scientific research, to improve our understanding of the environment at the time that they were deposited. Exposures of the *Rozel Conglomerate Formation* are typically like those seen elsewhere but are probably some of the most accessible exposures of this formation on the Island. Similarly, the head deposits are fairly typical compared to those seen elsewhere on the Island, but the accessibility and safety of the site gives them value.

Assessment of Site: Current site usage	
Community	Fliquet is located in a quiet corner of Jersey, where there are few local inhabitants. There are no cafés or toilets at the site, but the site is used for general recreational purposes. Existing walking and cycle routes pass the site.
Education	The site displays a variety of features. Unfortunately, the peat beds, which are the main feature of geological interest, are not generally visible. Exposures of the conglomerate are good and easily accessible, and the cliff sections show good examples of raised beach and head deposits. As the site can be viewed from the car park, a geological interpretation board beside the existing historical board would likely be well read and might encourage visitors to explore less accessible sites. The site could easily be part of a geological trail, as it already sits on walking and cycling routes around the Island.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Like all coastal locations, the site is subject to high-energy weathering and erosion. However, the peat beds are generally protected by a covering of sand and gravel, the bedrock exposures are extensive and fairly robust and the cliff sections are above the normal high-tide mark.
Potential use	This is the only site in Jersey known to contain peat beds of this age. There is therefore the potential for further scientific work to be carried out here.

Site Photos:

Photo 1: General view of the site from the car park. The peat beds lie in an elongate depression beneath the gravelly beach deposits. The shape of the depression is shown by the protruding bedrock exposures of the *Rozel Conglomerate Formation*. Looking east. BGS © UKRI 2020.

Photo 2: View across the car park at Fliquet Bay toward Fliquet Tower. A geological interpretation board could sit alongside the existing interpretation board that describes the tower. BGS © UKRI 2020.

Photo 3: Typical intertidal exposure of the *Rozel Conglomerate Formation*. The pebbles and cobbles within the conglomerate are well rounded to sub-rounded and composed of a variety of rock types. The unsorted nature of the conglomerate (i.e., different sizes of pebbles all mixed up) may indicate a mass flow deposit. Most of the loose beach pebbles have likely been sourced from the conglomerate. BGS © UKRI 2020.

Photo 4: A well-rounded boulder within the *Rozel Conglomerate Formation*. The clast size is indicative of the energy of the flow that supplied the sediment – the larger the pebbles, the higher the energy of the flow must have been. The clast shape is indicative of how far the clast has been transported – a well-rounded boulder composed of hard igneous rock (as seen in the image) has probably travelled a considerable distance from where it was sourced. BGS © UKRI 2020.

Site Photos:

Photo 5: A small discontinuous channel filled with fine-grained maroon sediments, sitting within the *Rozel Conglomerate Formation*. BGS © UKRI 2020.

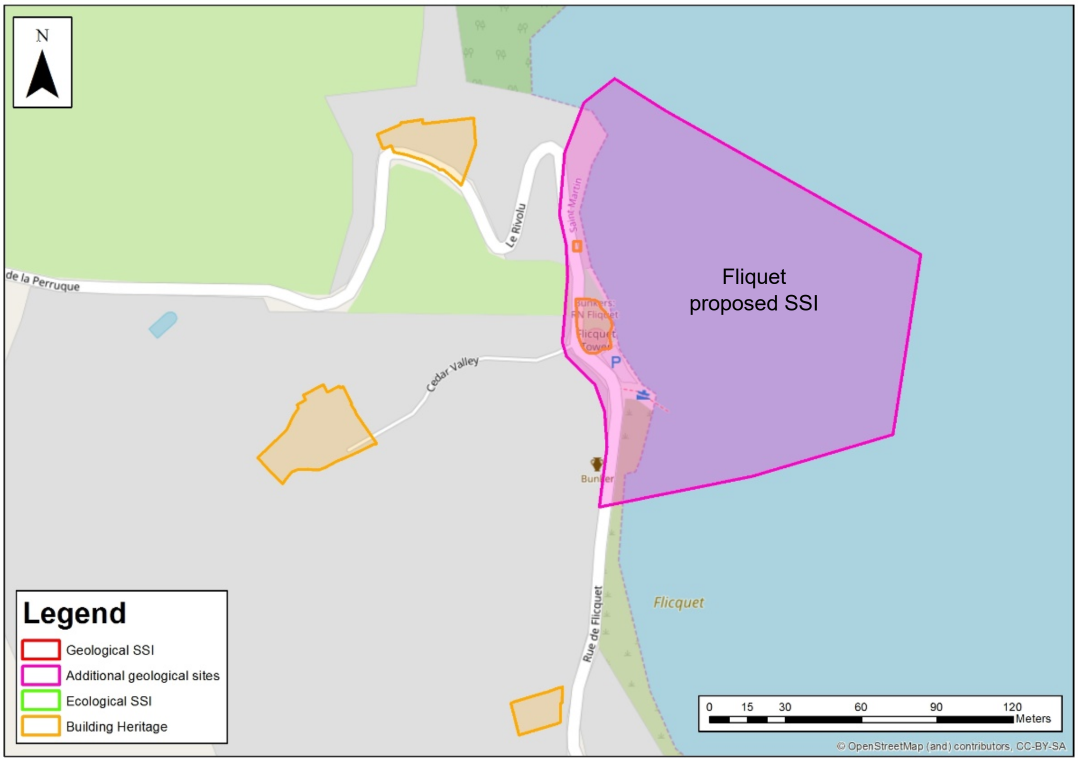
Photo 6: Cliff section through head deposits. Looking north. BGS © UKRI 2020.

Site Photos:

Photo 7: Cliff section at the back of the beach showing bedded head deposits. The deposits are dominated by cream-coloured silt with some gravel layers. The contact between the eroded top of the bedrock and the base of the head deposits is clearly seen. BGS © UKRI 2020.

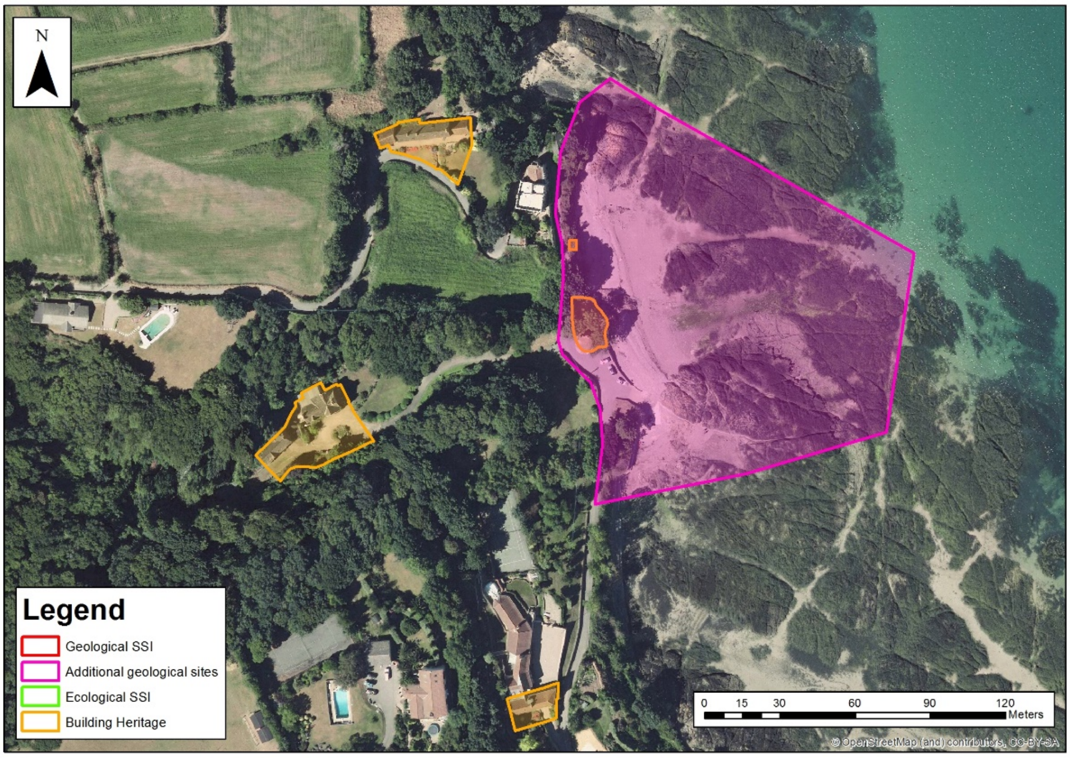
Photo 8: Close-up of head deposits extending behind the sea wall at the back of the beach. Looking west. BGS © UKRI 2020.

Map of the site boundary on a topographic base



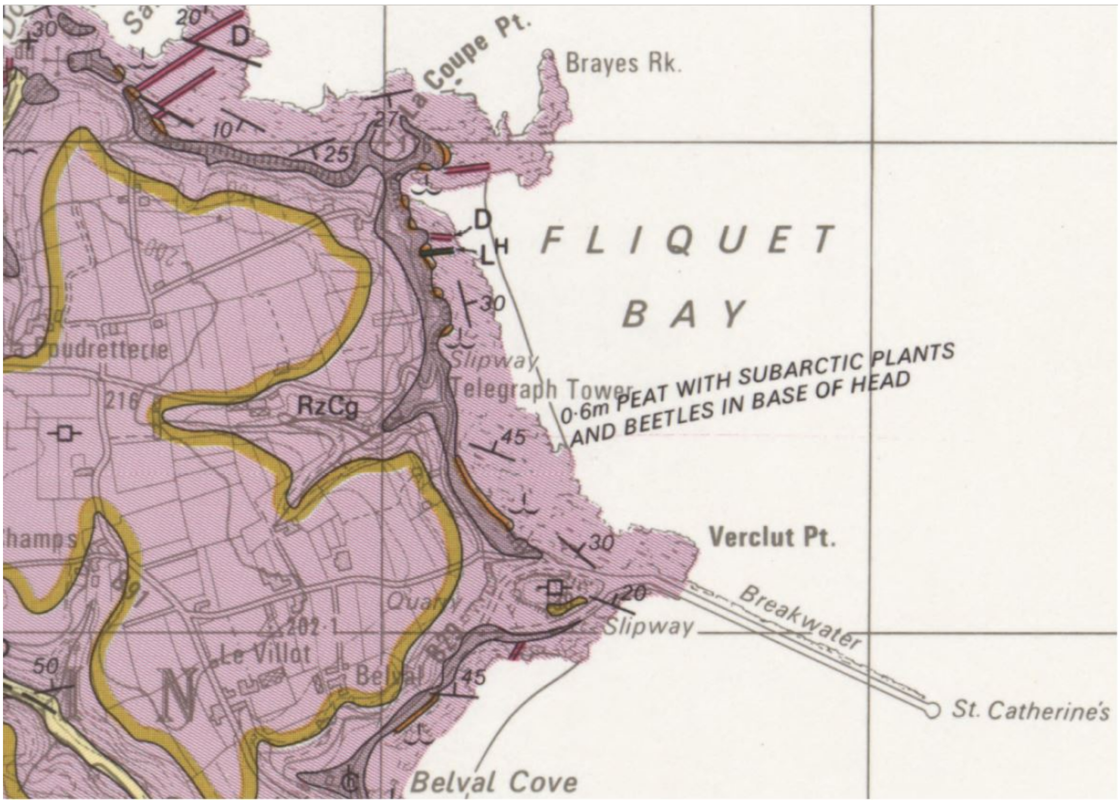
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

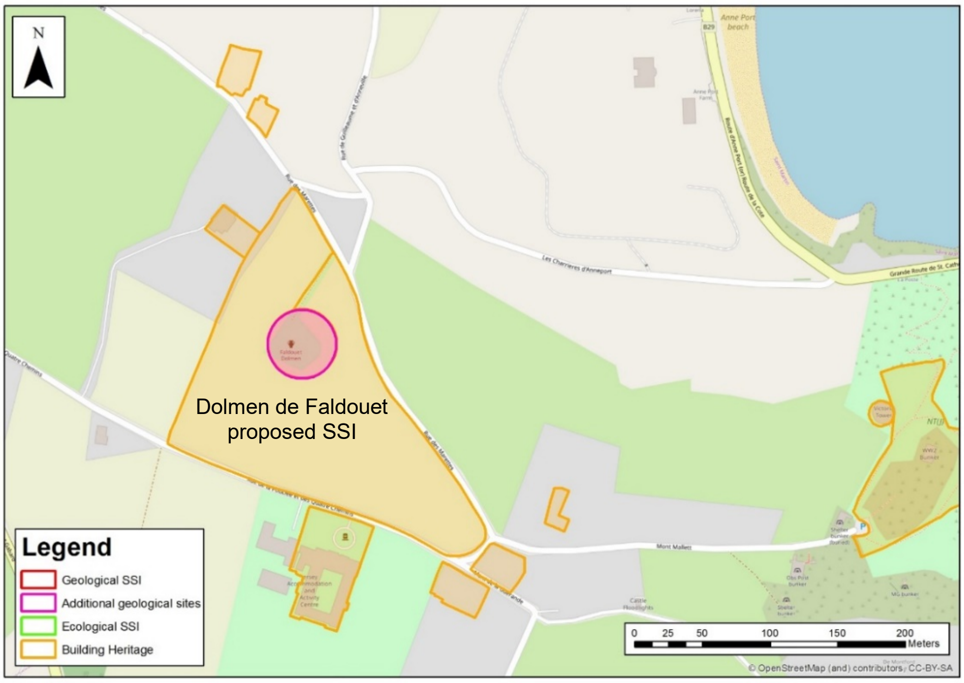


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

8.3 SITE NAME: DOLMEN DE FALDOUET, PROPOSED SSI

Site Information:	
The Dolmen de Faldouet (or La Pouquelaye de Faldouet) site is located on a hill inland of Anne Port Bay on Jersey's east coast. It is primarily an archaeological site featuring one of the Island's most impressive passage graves from the Neolithic Period. The geological interest lies in the different rock types and the origin of the stones used to construct this Neolithic structure, in particular, a single massive capstone of autobrecciated flow-banded rhyolite, which covers the circular burial chamber at the end of the stone-lined passage.	
National Grid Reference: Mid-point: 47891, 67558 West end: 47866, 67558 East end: 47917, 67558	**Site Type:** Archaeological structure
Site Ownership: To be confirmed	**Current Use:** Historical site
Field Surveyors: S Arkley and C Auton	**Current Geological Designations:** None
Date Visited: 16 October 2019	**Other Designations:** Building Heritage: La Pouquelaye de Faldouet (MN0224) covers the same area as the proposed geological site, and La Pouquelaye de Faldouet 2 (MN0305) surrounds the proposed geological site.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran (late Precambrian)	**Formation:** *Jersey Volcanic Group*
Rock Types: Auto-brecciated flow-banded rhyolite	

Site Description:

The Dolmen de Faldouet site is geologically interesting due to the rock types used for the construction of the passage grave; the rocks appear to have been sourced from a number of localities. Jersey has a large number of Neolithic dolmen and passage graves, many of which are freely accessible.
Although this site is traditionally referred to as a dolmen, it is more properly called a passage grave, which is a type of megalithic tomb that usually consists of two or more vertical megaliths supporting a large, flat, horizontal capstone or 'table'. Most dolmen and passage graves date from the early Neolithic, and they were sometimes covered with earth or smaller stones to form a tumulus.

This Neolithic passage grave was built around 6,000 years ago (*c.* 4,000–3,250 BC) and consists of a passage leading into an unusual double chamber (Photo 1). The main chamber is open and surrounded by a series of small stone cists (boxes), while the end chamber is covered by a massive 24-ton capstone. The whole site was originally encircled by a low mound with two drystone walls and a ring of upright stones. The site was first recorded in 1682 and was excavated three times, in 1839, 1868 and 1910, by the Société Jersiaise. Human bones from at least three adults and two children, including a complete skeleton in a seated position in one of the side chambers, were found, as well as three complete plain bowls, a small 'pigment cup', two vase supports (on which sat two of the bowls), flint tools, two polished stone axes, rubbers, hammers, greenstone and dolerite pendants.

The dolmen at the Dolmen de Faldouet site is one of the two Jersey monuments aligned with the solar equinox. It is a well-known feature on the Island; its image appeared on the Jersey 10p coin. The geological interest of this site lies in the composition of the rock types used to construct this Neolithic grave and the locations that these rocks were sourced from.

Of particular interest is the single massive capstone, which covers the end chamber (Photo 2). The stone, which is estimated to weigh 24 tons, is composed of an autobrecciated flow-banded rhyolite (Photos 3 and 4). The Dolmen de Faldouet site lies within the outcrop of the Jeffery's Leap Ignimbrite, which forms the lowest unit within the St John's Rhyolite Formation; this formation is exposed on the cliffs and foreshore around Anne Port Bay. Lithologically similar silica-rich volcanic rocks include the Anne Port Ignimbrite, also of the St John's Rhyolite Formation, and the Anne Port and Giffard rhyolites within the overlying Bouley Rhyolite Formation (see the Anne Port site description for further details). All of these units represent the exposures of the autobrecciated, flow-banded rhyolites that are nearest to the Dolmen de Faldouet site and therefore may have been the source of the large capstone.

Acid volcanic flows have a greater viscosity than basic basaltic lavas (which typically produce sheet-like flows that can cover tens of km^2). As a result, rhyolitic flows are rarely thought to travel more than a few kilometres from the volcano and may have thicknesses of up to 30 m. Autobrecciation occurs when the viscous, silica-rich lava or pyroclastic flow develops a solidified crust. This crust is subsequently broken up and fragmented by the continued movement of molten rock within the interior of the flow (Photo 3). Stressed and deformed by the movement, the crust fractures in a brittle manner, producing angular, smooth-faced blocks that are able to weld together. The relative intensity of autobrecciation is thought to be related to the velocity of the flow and the relative cooling of the lava or volcanic ash.

A number of the upright stones bounding the passage and forming the cists are made of medium- to coarse-grained, orange-pink granite and granodiorite (Photo 4), which were probably sourced from the *South-east igneous complex*. This plutonic igneous complex, which includes similar rock types to those found within the dolmen, is exposed on the headland and foreshore at Mont Orgueil, less than 1 km to the south-east of the site. Further identification of the rocks used in the construction of the grave may be possible, but it would require a detailed petrographic analysis of the rocks at the site and a comparison with petrological descriptions of potential source material from the surrounding area. Importantly, the Dolmen de Faldouet site is not located close to any inland natural rock exposures. Consequently, it must have taken a considerable amount of effort to transport the blocks used in the construction of the dolmen to the site, in particular the single massive capstone.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Limited roadside parking is available along the Rue de Marettes to the north of the site. However, the lane is narrow, so it is probably not suitable for minibuses or coaches. Visitors should take care not to block local entrances when parking cars. There are, however, a number of buses that stop locally (within 1 km of the site).
Access to site	Free, open access to the site. Five broad steps accompanied by a small information board on the south side of the Rue de Marettes show the start of a narrow, hedge-lined footpath that leads to the site. It is approximately 50 m from the road to the site.
Safety of access	Good. The path can be a bit muddy in poor weather and may get a little overgrown in the summer months – some regular pruning is likely required.
Safety of exposure(s)	A series of upright stones support the large capstone, which, although it may look a little precarious, has, as far as we know, rested there safely for thousands of years.
Current condition	It is understood that an increasing number of people are visiting the site, which is of some concern. During the site visit, areas of the site were fenced off to avoid further damage and allow recovery and repair. A permanent board could be erected to politely request that visitors respect the significance and fragility of the structure.
Current conflicting activities	None known
Restricting conditions	None known
Nature of exposure(s)	Part of an archaeological monument
Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	One of the best examples of a passage grave on the Island. It dates from the Neolithic Period and is approximately 6,000 years old. It is thought that the dolmen inspired several lines in Victor Hugo's *Les Contemplations*, written during his exile in Jersey in the 19th century. La Pouquelaye de Faldouet is a Neolithic passage grave from *c.* 4,000 BC (HER Number

	0700224; Listed place MN0224). Lithic scatter (HER Number 0700366). Nearby is Haut de la Garenne, a residential institution built in 1854 (HER Number 0700062; Listed building MN0062). The Royal Naval Training School is a collection of buildings that were formerly part of a naval training school founded *c.* 1860 (HER Number 0700245; Listed building MN0245).
Aesthetic landscape	Surrounded by farmland
History of Earth science	No associations known
Economic geology	No associations known

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy	Not applicable			
Sedimentology				
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The site is probably one of the earliest examples on the Island of stone being used for construction. It also displays the strength, ingenuity and determination of the people at that time: they managed to haul a massive capstone, probably from the nearby coastal bedrock exposures, to the site.

Assessment of Site: Current Site Usage	
Community	The site is frequented by visitors who want to see the dolmen on a regular basis. Old postcards of the site from 1914 (found on the internet) suggest that the site has probably always been a place of interest to locals and visitors.
Education	Large stones of different rock types were used to construct the passage grave. Stones of this size were most likely sourced from the coast, which suggests that they were brought from different parts of the Island. There is an interesting story to be told regarding where the stones have come from (indicated by their lithology and structures) and how they were transported. A clearer understanding of the rock types and structures may also help to better preserve the monument for future generations.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	This site is extremely vulnerable to vandalism.
Potential use	It is a good, accessible place that could be used to teach people about geology in a human context – in terms of building stones. This site already has interpretation boards, which could be augmented so that they mention more about the geology of the stones.

Site Photos:

Photo 1: The main passage of the Dolmen de Faldouet, bordered by upright stones and leading to the two-chambered tomb. BGS © UKRI 2020.

Photo 2: The massive table or capstone of the Dolmen de Faldouet, which is estimated to weigh on the order of 24 tons. BGS © UKRI 2020.

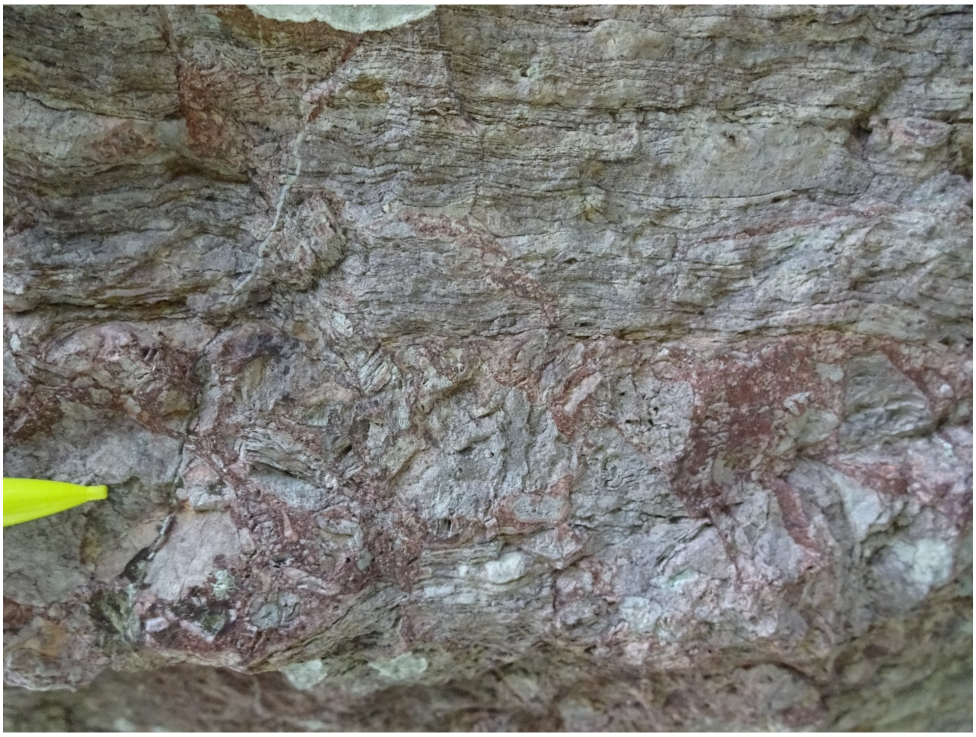


Photo 3: Autobrecciation within the flow-banded rhyolite capstone at the Dolmen de Faldouet. BGS © UKRI 2020.

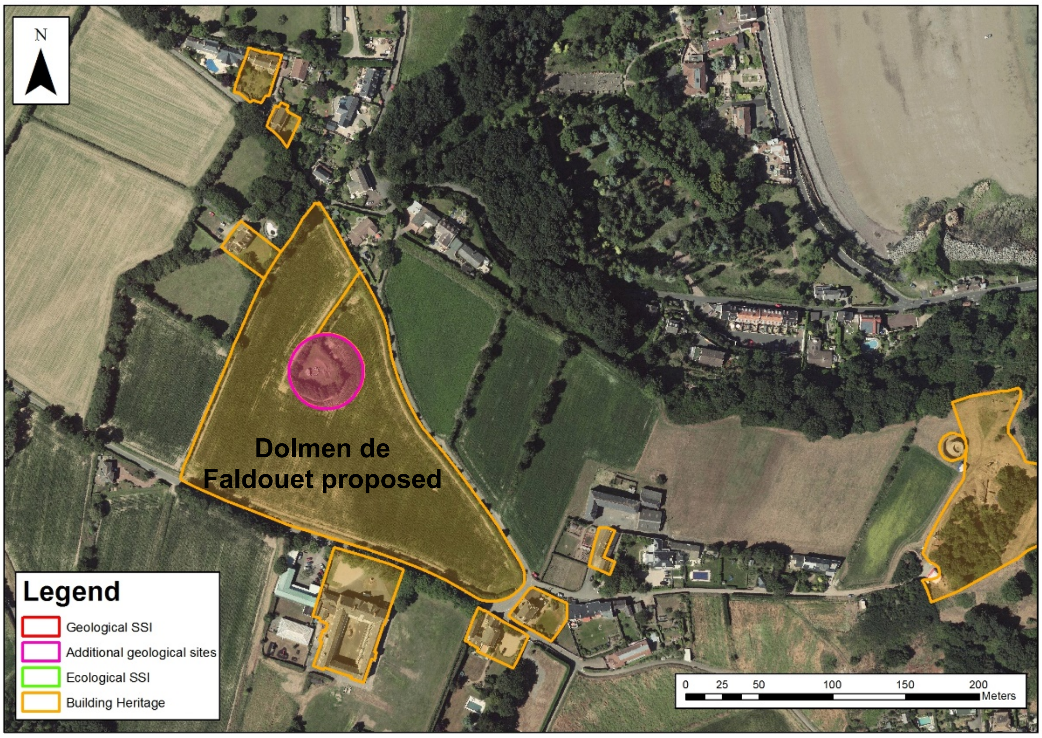
Photo 4: Flow banding in the capstone of the Dolmen de Faldouet. BGS © UKRI 2020.

Photo 5: Medium-grained pink granite, forming one of the upright stones that flank the passage to the burial chamber of the Dolmen de Faldouet. Similar granite crops out around Mont Orgueil, less than a kilometre to the south-east of the site. BGS © UKRI 2020.

Map of the site boundary on a topographic base

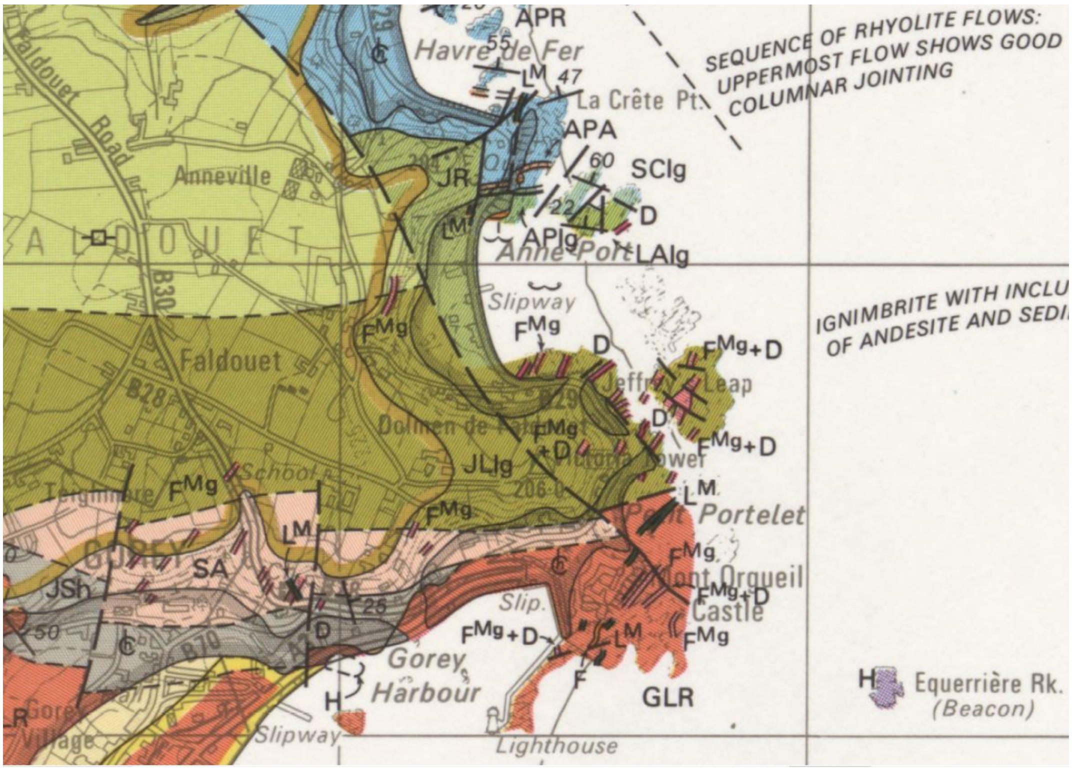
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

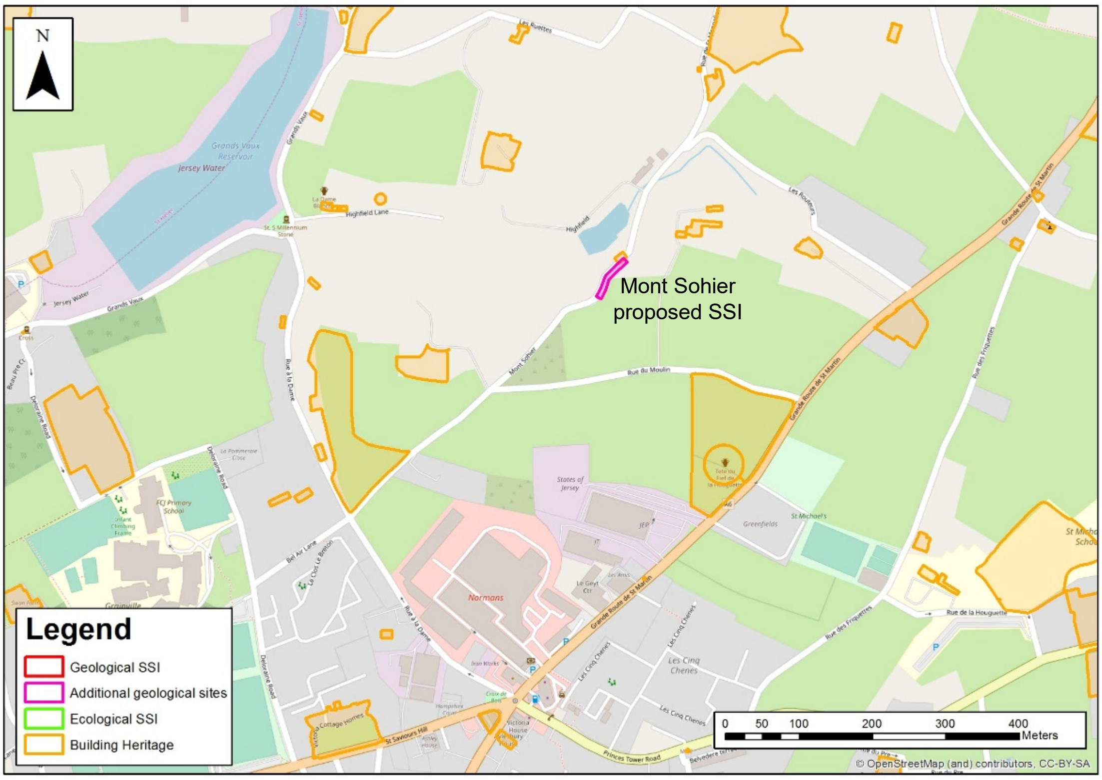


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

8.4 SITE NAME: MONT SOHIER, PROPOSED SSI

Site Information:	
The Mont Sohier site provides a rare inland exposure of the St Saviour's Andesite Formation, which displays pillow-like structures in a roadside cutting near Highfield Vineries. Although they are heavily weathered, 'pillows' measuring 10 cm in size can been seen in the andesite lavas, which display spheroidal weathering. The andesite lavas may represent the eruptive equivalent of the South-west and *South-east igneous complex*es, which were emplaced during the Cadomian Orogeny. The site is important because of the presence of possible pillows within the andesite lavas, which indicates eruption into a body of water. Gravelly head with angular clasts of andesite is exposed beneath loessic soil in an adjacent cutting.	
National Grid Reference: Mid-point: 44056, 67603 North end: 44077, 67628 South end: 44047, 67572	**Site Type:** Artificial section (road cutting)
Site Ownership: To be confirmed	**Current Use:** Urban
Field Surveyors: S Arkley and C Auton	**Current Geological Designations:** None
Date Visited: 17 October 2019	**Other Designations:** Building Heritage: La Forge (SA0061) lies at the northern end of the site.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** St Saviour's Andesite Formation
Rock Types: Tuff and pyroxene andesite	
Age: Quaternary	**Formation:** Head
Rock Types: Angular clast-supported gravel	

Site Description

Introduction

The Mont Sohier site provides a rare inland exposure of the St Saviour's Andesite Formation, which displays pillow-like structures. These 'pillows', measuring 10 cm in size, can been seen within the andesite lavas. More research is required but it is possible that these are pillow lava structures; however, other researchers suggest that the shapes are the result of spheroidal weathering. The andesite lavas may represent the eruptive equivalent of the South-west and *South-east igneous complex*es, which were emplaced during the Cadomian Orogeny. The site is important because of the presence of possible pillows within the andesite lavas, which indicate eruption into a body of water (Lees and Roach, 1993).

Bedrock Units

St Saviour's Andesite Formation (Jersey Volcanic Group)

The rocks of the St Saviour's Andesite Formation exposed in the road cutting at Mount Sohier (Photo 1) display possible pillow structures, indicating that they were erupted into a body of water (Photos 2–5). The mineralogy of these rocks is unknown, as no detailed description of them has been undertaken, apart from a small photograph on the Jersey Geology trail's website (http://www.jerseygeologytrail.net/index.shtml). The exposures at Mont Sohier are highly weathered, which makes describing the composition and grain sizes of these rocks difficult. Spheroidal (onion-skin) weathering, comparable to that developed in the mica-lamprophyre dyke exposed at the South Hill Site, is well developed (Photo 4). Other examples of spheroidal weathering can be seen near the lighthouse at Sorel Point and in the cliffs north of Grève de Lecq pier. The 'teardrop' shape, and the observed concentric and radial fracture patterns, which are associated with several of the 'pillow' features at the Mont Sohier site (Photos 3 and 5), are consistent with pillow lavas described elsewhere. If the features at the Mont Sohier site are pillows, then their bulbous, teardrop shape suggests that the St Saviour's Andesite Formation at this site is the right way up, and that the formation, dipping at up to 35–40°, becomes progressively younger towards the south-west.

Elsewhere in Jersey, the St Saviour's Andesite Formation consists of subaerially erupted lavas, tuffs and agglomerates of andesitic and basaltic composition (Bishop and Bisson, 1989; Lees and Roach, 1993). All the lavas contain numerous plagioclase phenocrysts, which, except in one basalt, have been altered to albite. The basalts all contained original olivine phenocrysts and most of the andesites contained original pyroxene, although in a few cases amphibole occurs instead. Most of the porphyritic andesite lava flows, tuffs and agglomerates and minor basalts are thought to have been deposited subaerially on the flanks of the volcano, but some may have been erupted into water, as the volcanic environment has been interpreted as one of a system of island arcs (Dupret *et al.*, 1990). Mineralogically, many of the andesitic rocks within the St Saviour's Andesite Formation have been classified as 'keratophyres' (Bishop and Bisson, 1989) in which primary albite has been altered to secondary oligoclase as a result of hydrothermal (hot water) alteration rather than low-grade regional metamorphism (Allaby and Allaby, 1990). Mourant (1933) also reported on 'spilites', which are fine-grained, highly altered basaltic igneous rocks. Spilite is formed when basaltic lava reacts with seawater or from hydrothermal alteration when seawater circulates through hot volcanic rocks; this lends weight to the idea that these rocks were erupted into water.

Dating

The *Jersey Volcanic Group* is divided into three formations: the St Saviour's Andesite (oldest), St John's Rhyolite and Bouley Rhyolite formations. The boundaries between these volcanic formations are commonly faulted, but regional mapping indicates that the sequence generally dips and becomes progressively younger towards the east (Thomas, 1977; IGS, 1982; Bishop and Bisson, 1989). The St Saviour's Andesite Formation rocks occur stratigraphically below the Bouley Rhyolite Formation, which includes the Anne Port Rhyolite. This rhyolite has yielded a U-Pb zircon age of 583 ± 3 Ma (Miller *et al.*, 2001), indicating that rocks of the St Saviour's Andesite Formation are older that *c.* 580 Ma.

Quaternary Sediments

Up to 2.5 m of gravelly head with well-sorted angular clasts of andesite is exposed beneath up to 1.5 m of loessic soil in an adjacent cutting located to the south-west (uphill) of the main bedrock exposure**.** The gravel head is clast-supported and shows moderately developed stratification, dipping at *c.* 25–30° towards the south-west**.** These characteristics indicate that the deposit resembles a scree, or talus, developed by the mechanical breakdown of rocks of the St Saviour's Andesite Formation by freeze-thaw action under periglacial conditions. The gravel appears to have undergone little downslope remobilisation due to solifluction, gelifluction or subsequent water movement, unlike most of the gravelly head deposits seen at sites around the coast. The contact with the overlying loessic soil is relatively sharp and planar, although there has been some downward translocation of loessic silt, particularly into the upper parts of the head gravel. The soil shows little internal stratification and has been penetrated by tree roots throughout.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	There are some places suitable for street parking on Mont Sohier Road in the vicinity of the site. However, the lane is narrow and winding, so it is probably not suitable for minibuses or coaches. Visitors should take care not to block local entrances when parking cars. Bus routes stop within a short walk of the site.
Access to the site	Easy access along the road; no known access restrictions
Safety of access	A short walk along Mont Sohier will likely be necessary to reach the site. The roads are single-lane, narrow and high-sided in places, so care should be taken in watching for traffic at all times.
Safety of exposure(s)	The site is a roadside exposure; care should be taken in watching for traffic when examining the section. The road is narrow and winding; hi-vis jackets and a look-out person would be advised if visitors want to examine the section close-up, as this would involve people standing on the tarmac road. The exposure itself appears to be relatively stable, but care should always be taken when beneath cliffs, particularly in any overhanging areas.
Current condition	Some areas are clear of vegetation, but others have a significant covering of ivy. Given how quickly ivy grows, the section would benefit from some cleaning to retain visible exposures.
Current conflicting activities	None known. However, the site has limited parking options and there are residential properties on the opposite side of

	the road, so encouraging large numbers of visitors may not be appropriate.
Restricting conditions	Cars parked along the side of the road in front of the section will limit access and visibility.
Nature of exposure(s)	Roadside cutting

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Fernside Farm, a property to the north-west of the site, is a 17th-century farmstead (HER Number 1100062; Listed building SA0062).
Aesthetic landscape	Located along a typical inland valley road. Les Routeurs, a road that lies 200 m north-east of the site, won the Scenic Lanes award in 2013.
History of Earth science	No known associations
Economic geology	No known associations

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Regional	Good	Detailed	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

This site is a good inland exposure of the St Saviour's Andesite Formation, displaying the only known pillow-like structures in the Island. The site is important because the presence of possible pillows in the lavas would indicate eruption into a body of water, supporting an island-arc origin for rocks of the *Jersey Volcanic Group*. It is very accessible for a quick stop and not restricted by tide times.

Assessment of Site: Current Site Usage	
Community	The site is unused, although people drive past it regularly and occasionally walk past it.
Education	This site is a great place to see igneous structures that are not seen elsewhere on the Island. However, the site would be more appropriate for smaller parties and those who already have some interest in Earth science.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The site is vulnerable to natural overgrowth and weathering.
Potential use	The site is potentially useful for research and those in higher education.

Site Photos:

Photo 1: View looking north-west down Mont Sohier Road. The road section displays volcanic units from the St Saviour's Formation. BGS © UKRI 2020.

Photo 2: Roadside section displaying pillow-like structures (to the right of the hammer) in the St Saviour's Andesite Formation. BGS © UKRI 2020.

Photo 3: Close-up views of pillow-like structures, up to 50 cm in diameter, in the St Saviour's Andesite Formation. BGS © UKRI 2020.

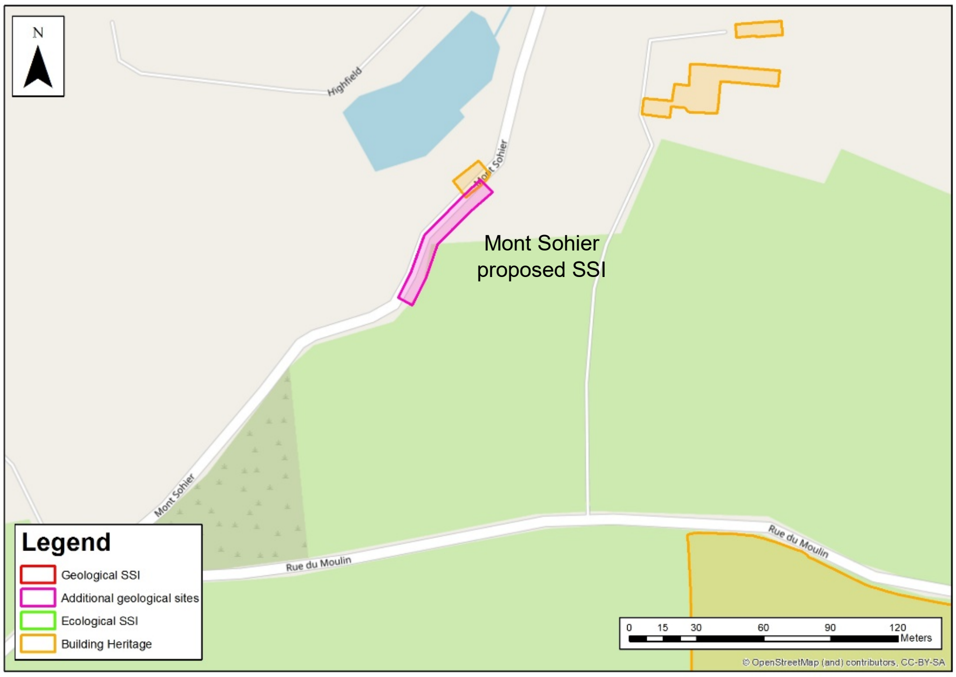
Photo 4: Close-up of the curved 'rind' of a pillow-like structure in the St Saviour's Andesite Formation. This may be due, in part, to concentric fracturing caused by the rapid cooling of the outer surface of the lava 'pillow' due to contact with water during its eruption. It may also be partly the result of subsequent spheroidal weathering, which typically occurs on exposures of fine-grained, basic volcanic rocks. BGS © UKRI 2020.

Photo 5: Close-up of a cross-section through the best-developed pillow-like structure in the St Saviour's Andesite Formation. Note the 'teardrop' shape and concentric and radial fracture patterns; these features are found in many pillow lava sequences. BGS © UKRI 2020.

Photo 6: Roadside section in clast-supported head composed of angular clasts of andesite, with stratification, dipping at *c.* 25–30° up-slope**.** This head deposit resembles a scree, or talus, developed by the mechanical breakdown of the St Saviour's Andesite Formation bedrock under periglacial conditions. BGS © UKRI 2020.

Photo 7: Close-up of the sharp contact between the head gravel and the overlying loessic soil; note the tree root in the upper left corner of the image. BGS © UKRI 2020.

Map of the site boundary on a topographic base

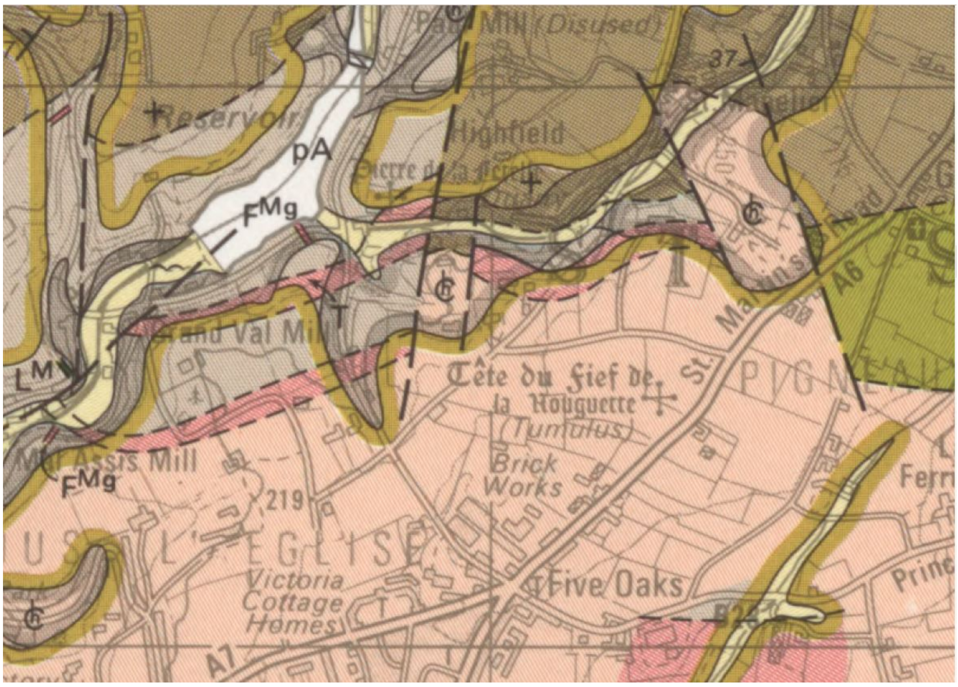


Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph

Imagery ©2020 Government of Jersey.

Published geological map of the site

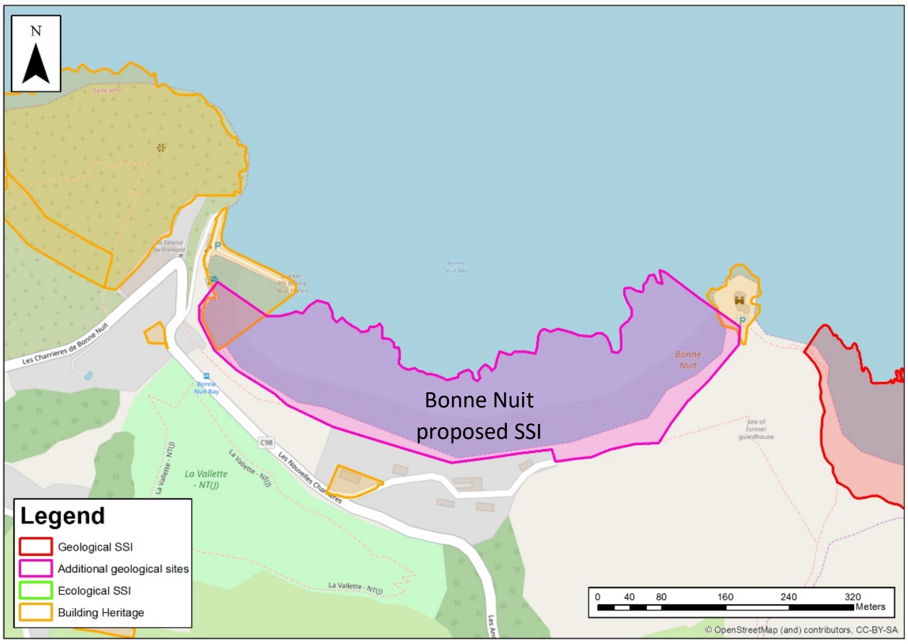


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

8.5 SITE NAME: BONNE NUIT, PROPOSED SSI

Site Information:	
Bonne Nuit is a north-facing coastal site, bounded to the east and west by rocky headlands and backed to the south by a cliff section cut into Quaternary deposits; part of this section includes the 8 m raised shoreline in the area. The head deposits at the site display evidence of evolving palaeoenvironments, with a rapid, dynamic change recorded by possible shallow lake or lagoon sediments, which were later buried by a large debris fan. The disturbance of the lake sediments shows that this burial may have taken place in a single, large event. The fan deposits locally directly overlie the pebbly gravel of the 8 m raised beach. Iron-cemented gravel plastered onto foreshore exposures of the Bonne Nuit Ignimbrite are thought to represent a remnant of the raised beach, indicating that it extends from near the present sea level up to *c.* 8 m above mean sea level. Exposures of volcaniclastic rocks of the St John's Rhyolite Formation occur at La Crête headland and in foreshore reefs in the eastern and middle parts of the site. The formation comprises a complex sequence of rhyolitic ignimbrites, andesitic agglomerates and tuffs, which display a wide variety of igneous textures and extrusive contacts. These features indicate that at least parts of the sequence were emplaced either in a subaqueous environment or on top of water-saturated sediments. The formation shows a transition from rhyolitic volcanic activity, typified by the Bonne Nuit Ignimbrite, through andesitic pyroclastic rocks and then back into rhyolitic activity, with the emplacement of the Frémont Ignimbrite. They therefore provide crucial evidence of the evolving volcanic environment during the eruption of the *Jersey Volcanic Group*.	
National Grid Reference: Mid-point: 41357, 72786 West end: 41026, 72900 East end: 41662, 72907	**Site Type:** Natural section/exposure
Site Ownership: To be confirmed	**Current Use:** Open country, coastal
Field Surveyors: J Everest, L Hughes, S Arkley and C Auton	**Current Geological Designations:** None
Date Visited: 26 September 2019 and 14 October 2019	**Other Known Designations:** Building Heritage: La Crête Fort (JN0138) overlaps with the eastern end of the site and Bonne Nuit Harbour (JN0042) overlaps with the western end of the site. Other: Areas above the HWM are within Jersey National Park.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran (late Precambrian)	**Formation:** St John's Rhyolite Formation
Rock Types: Frémont Ignimbrite, Bonne Nuit Agglomerate, Bonne Nuit Andesite, Bonne Nuit Tuff, Andesitic Agglomerate and Bonne Nuit Ignimbrite	
Age: Uncertain but possibly Silurian	**Formation:** Lamprophyre dykes
Rock Types: Mica lamprophyre	
Age: Quaternary	**Formation:** Raised beach
Rock Types: Rounded pebble and cobble gravel	
Age: Quaternary	**Formation:** Head
Rock Types: Bouldery, cobbly and loessic head	
Age: Quaternary	**Formation:** Head
Rock Types: Aqueous, silty, clay sand	
Age: Quaternary	**Formation:** Head
Rock Types: Coarse, angular fan deposits	

Site Description:

Introduction

This site comprises a number of rocky and vegetated cliff sections bounding Bonne Nuit, and numerous bedrock exposures on the foreshore, notably at the eastern end of the site. These cliffs are cut in a relatively complex periglacial Quaternary sequence that in places overlies deposits of the 8 m raised beach, which is exposed at the base of the cliff. The development of housing and sea defences has resulted in several former sections through the Quaternary succession being obscured from detailed examination and has slightly decreased the geoscientific importance of the site since it was described by Keen and others during the 1990s. The remaining sections exposed in the cliffs still provide a good opportunity to examine environmental changes during the Quaternary, with evidence of early periglacial conditions, a lake or lagoon, and a sudden inundation by mass movement deposits. The best exposed bedrock units occur at the eastern end of the site, where a variety of extrusive volcanic rocks, representing the upper part of the St John's Rhyolite Formation of the *Jersey Volcanic Group*, can be examined. These rocks are predominantly andesitic in composition and include agglomerates, ignimbrites and tuffs. The rhyolitic Bonne Nuit Ignimbrite forms the bedrock underlying much of the middle and western portion of the site. Both the Quaternary and bedrock exposures are most easily accessed by walking eastwards along the beach from the harbour at Bonne Nuit. The bedrock exposures can be accessed more directly from a steep path that descends the cliff to reach the foreshore, just west of the fort on the La Crête headland.

Bedrock Units

St John's Rhyolite Formation (Jersey Volcanic Group)

The volcanic rocks at Bonne Nuit Bay form part of the Ediacaran (late Precambrian) *Jersey Volcanic Group*. They are one of the three principal known occurrences of calc-alkaline volcanic rocks associated with the Cadomian orogenic belt of North-west France and the adjacent Channel Islands (Lees and Roach, 1993), with the sequences in Jersey being the best exposed of the three. The other occurrences are the Tufs de Trêguier and Ignimbrites des Lêzardrieux, in Brittany (Auvray, 1989), and the Serie volcano-sedimentaire et complexe ignimbritique de St Germain-le-Gaillard, in Normandy (Graindor, 1957; Graindor *et al*., 1976). The *Jersey Volcanic Group* is divided into three formations: the St Saviour's Andesite Formation (oldest), St John's Rhyolite Formation and Bouley Rhyolite Formation (youngest). However, at Bonne Nuit Bay, the volcanic sequence is dominated by the rhyolites, andesites, tuffs, ignimbrites and agglomerates of the St John's Rhyolite Formation (IGS, 1982; Bishop and Bisson, 1989). At this site, the formation is subdivided into six informal units, namely the Bonne Nuit Ignimbrite (oldest), Andesitic Agglomerate, Bonne Nuit Tuff, Bonne Nuit Andesite, Bonne Nuit Agglomerate and Frémont Ignimbrite (youngest). The stratigraphical relationships between the upper part of the Bonne Nuit Ignimbrite and the overlying Bonne Nuit Tuff and Bonne Nuit Andesite are represented in the vertical section constructed by Thomas (1977), which was reproduced by Bishop and Bisson (1989, figure 8). The published geological map (IGS, 1982) indicates that the sequence generally becomes younger and dips at *c.* 50–85° towards the north-east. However, locally, some of the contacts dip at up to 85° towards the south-west.

The key issue for anyone visiting Bonne Nuit is recognising the individual units within the St John's Rhyolite Formation, as many of the contacts are subtle and difficult to trace because they have been modified by later faulting and/or are obscured by seaweed and algae. Furthermore, it is evident from the work by Lees and Roach (1993) that the *Jersey Volcanic Group* exposed at the site comprises 'mixed assemblages' of volcanic and sedimentary rocks, occurring not only within the Bonne Nuit Agglomerate, Bonne Nuit Andesite and Bonne Nuit Tuff, but also between the Andesite Agglomerate and the Bonne Nuit Ignimbrite. These authors also record the presence of 'acidic sheets in mixed rocks' at the top and at the base of the Andesitic Agglomerate. However, neither these acidic sheets nor the mica-lamprophyre dyke mapped by Thomas (1977) cutting the Bonne Nuit Ignimbrite were recognised during the site visit.

The Bonne Nuit Ignimbrite (450–600 m thick; Bishop and Bisson, 1989) is the oldest unit within the St John's Rhyolite Formation, and it is exposed in the middle and western parts of the site. The dominant rock type was described by Lees and Roach (1993) as a welded tuff, and subsequently by Bishop *et al*. (2003) as a silicified rhyolitic ash that is commonly grey to black in colour on fresh surfaces (Photo 15), but weathers to a pale cream to yellow (Photo 17). A well-developed eutaxitic fabric occurs throughout the unit, with variably flattened fiamme forming up to 10% of the rock. Autobrecciated units, thought to represent the tops of individual flows, are recorded by Bishop and Bisson (1989), but no clear examples were seen during the visit for this audit. A near-vertical layering is evident in some exposures (Photo 17), but elsewhere the rock has a broken-up or rubbly appearance (Photo 18), which may represent the rubbly bases of the individual rhyolitic flows or may be the result of later tectonic fracturing. A weakly metamorphosed, possibly cross-bedded sandstone (Photo 16) was seen within an outcrop near the top of the Bonne Nuit Ignimbrite. However, it is unclear whether this is a large clast within the ignimbrite or part of the mixed assemblage of sandstone, siltstone and mudstone recorded by Lees and Roach (1993).

The Bonne Nuit Ignimbrite is shown, on the geological map (IGS, 1982), to be overlain by the Andesitic Agglomerate (Photos 12–14). Bishop and Bisson (1989) describe the agglomerate as being up to 63 m thick, and although this is not shown on their vertical section, it may, at least in part, correspond to the basal surge deposits that appear to overly the Bonne Nuit Ignimbrite (Bishop and Bisson, 1989, figure 8). These authors suggest that the Andesitic Agglomerate can be divided into three layers: the lowermost layer is characterised by the presence of andesite clasts containing pink albitised plagioclase phenocrysts, the middle layer by aphyric andesitic rock fragments and the uppermost layer by andesite containing white (possibly unaltered) plagioclase phenocrysts.

The Andesitic Agglomerate is in turn overlain by the Bonne Nuit Tuff (Photo 11), which was described by Bishop and Bisson (1989) as a light grey, fine-grained tuff containing euhedral to subhedral feldspar crystals and shards of pumice. The Bonne Nuit Tuff is shown to be up to *c.* 25 m thick on the vertical section (Bishop and Bisson, 1989, figure 8), and it is shown to be cut out by the basal surge deposit of the overlying Bonne Nuit Andesite. The Bonne Nuit Andesite (60 m thick; Bishop and Bisson, 1989) is composed of a fine-grained, dark greenish andesitic rock with locally well-developed peperitic margins (Photo 10). The published geological map (IGS, 1982) indicates that its upper contact with the overlying Bonne Nuit Agglomerate and its basal contact with the underlying Bonne Nuit Tuff are generally conformable. However, Lees and Roach (1993) record the presence of a 'mixed assemblage' of rocks occurring between the top of the Bonne Nuit Tuff and the base of the overlying Bonne Nuit Andesite. The authors suggest that these mixed rocks provide evidence that the andesitic flows were emplaced onto 'the debris flows of the mixed assemblage, when the latter were in an unconsolidated state'. These may be equivalent to the base surge deposit at the base of the Bonne Nuit Andesite shown in Bishop and Bisson (1989, figure 8). However, because Lees and Roach (1993) did not adopt the earlier stratigraphy used by Thomas (1977) and Bishop and Bisson (1989), it is difficult to reconcile the often-significant differences in the volcanic sequences described by these researchers.

The Bonne Nuit Agglomerate, overlying the Bonne Nuit Andesite, crops out on the foreshore immediately to the east of La Crête headland (Photo 8). This *c.* 30-m-thick, dark grey, felsic to andesitic volcanoclastic unit contains blocks of andesite up to 1.5 m in diameter (though most are only a few centimetres in diameter) in a fine-grained matrix. Peperite margins are common within individual beds of agglomerate (Photo 9), indicating that these rocks were erupted into an aqueous environment or onto water-saturated sediments (Lees and Roach, 1993). The geological map (IGS, 1982) shows that at La Crête, the easterly dipping Bonne Nuit Agglomerate is faulted against the Frémont Ignimbrite, which dips westwards.

The Frémont Ignimbrite is the uppermost (youngest) unit of the St John's Rhyolite Formation exposed at the Bonne Nuit site. It comprises a sequence of light grey, flow-banded ignimbrite and agglomerate, which are exposed in the cliffs on La Crête headland (Photo 8). These cliff exposures were too steep and dangerous to examine in detail, and it is recommended that the Frémont Ignimbrite be examined at the Giffard Bay site (see the Giffard Bay site description). Bishop and Bisson (1989) state that the Frémont Ignimbrite is 160 m thick at its type site at Frémont Point, on the western side of Bonne Nuit Bay, thinning to *c.* 100 m thick at La Crête. At Frémont Point, Bishop and Bisson (1989) recognised four individual flows within the Frémont Ignimbrite and an upper, fifth unit composed of multiple thin flows. Eutaxitic textures are common throughout the ignimbrite unit, with the individual flows being separated by erosional bases and basal surge-type deposits. The recrystallisation and/or devitrification of the originally glassy fiamme is common. The ignimbrite contains clasts of shale, tuff and agglomerate, with clast-rich zones forming the rubbly bases of the individual flows. Bishop and Bisson (1989) suggest that at La Crête, the distribution of clast-rich zones within the Frémont Ignimbrite indicates that the unit is overturned (this observation was not verified during the site visit). At Giffard Bay, the Frémont Ignimbrite underlies the Giffard Rhyolite of the Bouley Rhyolite Formation. This Giffard Rhyolite has been correlated with the Anne Port Rhyolite, which was dated to 583 ± 3 Ma (U-Pb zircon age) by Miller *et al.* (2001). If these units are in fact correlated, this suggests that the eruption of the Frémont Ignimbrite and therefore the remainder of the underlying St John's Rhyolite Formation at Bonne Nuit Bay predate *c.* 583 Ma.

Minor intrusions

The only minor intrusion present at Bonne Nuit Bay was a N–S-trending mica-lamprophyre dyke, which intruded into the Bonne Nuit Ignimbrite where it was exposed close to the low water mark in the middle of the site.

Quaternary Sediments

At Bonne Nuit, the Quaternary sediments resting directly upon the St John's Rhyolite Formation are most clearly exposed at the eastern and western ends of the site, as netting covering the cliff section in the middle of the bay has led to the accumulation of washed-out material, which obscures the underlying geology. To the western end of the bay, closest to the harbour, a small section at the base of the cliff reveals a well-cemented gravel composed of rounded pebbles exposed beneath bright orange, silty loessic head (Photo 1). This pebbly gravel has been interpreted by Keen (1993) as being part of the 8 m raised beach. Another pebbly unit, comprising angular cobbles, rests, with an irregular erosional contact, on the loessic head. However, apart from a small exposure at the base of a cliff near the eastern end of the site (Photo 6), no other exposures of the loessic head described by previous researchers were visible at the time of the present survey.

On the foreshore in the middle of the site, exposures of the St John's Rhyolite Formation are capped by an iron-cemented gravel, comprising rounded clasts up to 5 cm in diameter (Photos 9 and 18) and interpreted by Bishop *et al*. (2003) as a Pleistocene beach deposit, which possibly equates to the 'submerged beach' of Mourant (1933). The pebbles include flint (5% of the gravel), which Bishop *et al*. (2003) suggest was probably derived from seabed outcrops of chalk to the north and the west of Jersey. Elsewhere at the Bonne Nuit Bay site, the basal part of the Quaternary sequence is represented by up to 4 m of stratified, clast-supported, angular cobble-to-pebble gravel head deposits (Photos 2–7). Variation in the dip of the bedding within these deposits has been used to suggest that they were deposited as a series of conical fans or aprons. In the eastern exposures, this head deposit is overlain by a thin, grey, fine-grained silty clay sand (Photo 4) possessing well-developed flame structures formed as a result of loading and the remobilisation of the sediment (Photo 5). Keen (1989) interpreted these finer-grained sediments as having been deposited in a series of small ponds or a lagoon that formed following the erosion of the upper surface of the underlying head deposit, possibly by wave action. Although they are not currently exposed, these fine-grained deposits have previously been described in the vicinity of the harbour and central sections of the site (Keen, 1989).

Overlying the fine-grained layer are 2–4 m of clast-supported, poorly sorted, weakly imbricated, angular, cobble to pebble gravels with a yellowish-brown, silty sand matrix. A variably developed stratification within these deposits dips towards the east at the eastern end of Bonne Nuit Bay and dips west at the western end of the bay. These coarse-grained head deposits are interpreted as having been deposited by fans sourced from the adjacent slopes enclosing Bonne Nuit Bay. Loading and water escape within the underlying fine-grained deposits suggests that these fans formed relatively rapidly, prograding into the lagoon. A possible palaeochannel, recognised in the vicinity of the retirement home, may have drained into the bay from the south.

Raised beaches

The evidence for past high relative sea levels is widespread in Jersey, Guernsey and Alderney, as well as on the Cotentin Peninsula and in Brittany. It includes wave-cut notches and platforms cut into the bedrock, as well as raised beach remnants, which occur at a wide range of elevations above the present mean sea level. Currently, six separate Quaternary high sea-level stands have been identified in Jersey, of which the 8 m raised beach is the most exposed around the coastline. This raised beach forms easily identifiable features, which are particularly prominent in Le Pulec (Renouf and James, 2011), Bonne Nuit, Bouley and Rozel bays in the northern part of the Island, and in Portelet and Belcroute in the south of Jersey (Keen, 1993, and Keen, *et al.*, 1996). The beach material is composed of a wide range of clast sizes, from 40 cm cobbles, such as those found at Portelet, to fine gravel and sand at Belcroute Bay. The 8 m beach sediments often overlie head deposits, and this, combined with some of the few dates derived using both U-series and AAR methods from the raised beach at Belle Hougue, have led Renouf and James (2011) to assign the 8 m beach an age of *c.* 121 ka BP, which correlates well with the wider Ipswichian/Eemian Period across Europe (Figure 2). This proposed age is in contrast to the previously favoured MIS 7 age postulated for these features across Jersey, which dates the formation of these features to between 245 and 186 ka BP (e.g., Keen, 1993). Without an extensive dating programme for these features, possibly using more modern applications (e.g., revised ^{14}C, thermoluminescence, terrestrial cosmogenic nuclides), this chronology cannot be more tightly constrained, and these differences in interpretation will remain.

Quaternary terrestrial deposits (head deposits)

During cold climate conditions, repeated freezing and thawing causes the frost shattering, erosion and disaggregation of exposed bedrock surfaces. The gravitationally driven downslope movement of this broken material, due to a combination of solifluction, gelifluction, debris flows and soil creep, can lead to the accumulation of significant thicknesses of material at the bases of slopes. These deposits, called 'head', are typically poorly sorted with little stratification, and their components range from boulders to silt; however, in some sequences, coarse bedding can be observed. Head thicknesses can reach up to 20 m along the base of ancient abandoned (palaeo) coastal cliff lines; the height of the palaeocliff is directly related to the thickness of the head deposit, with a ratio of cliff height to head thickness of *c.* 4 or 5:1 (Keen, 1993).

Head deposits occur at many coastal locations across Jersey and have been observed forming fans and cones beneath the blown sand in the St Ouen's, St Aubin's and St Clement's bays. At Portelet and Belcroute, up to 2 m of head, directly overlying bedrock, can be seen beneath the gravels of the 8 m raised beach, leading to the assumption that these periglacial slope deposits are pre-Ipswichian in age. The thickest accumulations of head occur at the Bonne Nuit and Bouley bays, where they are up to *c.* 30 m thick. Notable features are described in the site reports. At Bonne Nuit Bay, the head exposed in the central and eastern part of the bay also contains subhorizontal grey silt layers, possibly indicating deposition into a lagoon (Bishop and Bisson, 1989) that was isolated on the foreshore as a result of falling sea levels. At La Cotte de St Brelade, the head deposits contain faunal remains and anthropogenic artefacts, including the bones of mammoths, rhinoceros, rodents and birds, along with the tools and bones of Neanderthals; as a result, the site is of international archaeological significance. At Fliquet Bay, peat containing beetle and pollen taxa, indicative of formation in a sub-Arctic environment, has been incorporated into the base of the head deposits. An infinite ^{14}C age that was obtained for the peat (Coope *et al.*, 1980) has been used to suggest that the sequence is Ipswichian in age; however, recent advances in radiometric dating techniques may argue for a reinvestigation of the site.

Head also occurs inland in Jersey; however, these inland deposits tend to be thinner, mantling the lower valley slopes to maximum depths of 2–3 m. The inland head deposits also tend to be finer-grained than those at the coast, because they are mainly derived from the loess on the plateau above.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	The bay is directly accessible by road, although parking is limited to the harbour side and the steep roadside above the harbour. There is a small private car park at La Crête Fort that is not for public use; it is only for visitors using the holiday let. This is not suitable for large vehicles such as coaches.

Safety of access	There is easy access to the shore, but all visitors should be aware of the tide times when planning a visit, as many of the exposures are only visible at low tide. The exposures on La Crête headland were regarded as too difficult and dangerous to examine during the site visit.
Safety of exposure(s)	The rocky foreshore is uneven, and the beach is made of large, rounded cobbles, which may make walking difficult for some. The foreshore exposures of bedrock are slippery when wet and many are covered by seaweed, barnacles and algae. The cliff exposures of Quaternary sediments are steep, and although they are well consolidated, there is a possibility of rock falls. A notable landslip occurred here in March 2016, causing the Cheval Roc retirement home to close temporarily.
Access	Along the foreshore and via slipways, or from the steep cliff path immediately west of La Crête
Current condition	Most of the Quaternary cliff sections are well exposed at the western and eastern ends of the bay. The central section is largely obscured by netting, which is in place to slow wave erosion and weathering beneath the retirement home. The bedrock exposures seem to be comparable to those examined during the mapping of the area in the 1990s.
Current conflicting activities	None known
Restricting conditions	Tides: Much of the exposure is accessed from the intertidal zone and is therefore inaccessible at high tide.
Nature of exposure(s)	Cliff exposures in the Quaternary sediment are between 2 and 8 m high. Bedrock is exposed in steep cliffs, La Crête headland and foreshore reefs.

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	La Crete Fort was built in 1834 (HER Number 0500138; Listed building JN0138). Furze Cottage was built *c.* 1903 with a design inspired by the Arts and Crafts Movement (HER Number 0500181; Listed building JN0181). Bonne Nuit Harbour is a boulevard built in 1871, and the jetty was built in 1872 (HER Number 0500042; Listed building JN0042). La Maison du Havre is a fisherman's cottage built *c.* 1780 (HER Number 0500012; Listed building JN0012). La Tete de Fremont is a defensive earthwork of a promontory fort, possibly dated to the Iron Age (*c.* 700–50 BC) or Medieval Age (*c.* 1200 AD; HER Number 0500093; Listed place JN0093). Greywacke axe (HER Number 0500257). Lithic scatter (HER Number 0500210).
Aesthetic landscape	Coastal landforms
History of Earth science	None
Economic geology	None

Assessment of Site: Geoscientific Merit	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Regional	Good	Detailed studies	X
Structural geology				
Palaeontology				
Geomorphology	Regional	Good	Detailed studies	X

Geoscientific Value of the Site
This site displays excellent cliff sections cut into Quaternary head deposits, which overlie gravels of the 8 m raised shoreline. The head is more variable in aspect than the head at many other sites on the Island and displays evidence of changing palaeoenvironments, which is not often evident at other sites. This evidence includes the recognition of a large debris fan inundating a shallow lake or lagoon. The disturbance of the subaqueous sediment shows that this burial may have taken place in a single, large event. The presence of iron-cemented gravel plastered onto foreshore bedrock exposures provides rare evidence to support the contention that the altitudinal range of the 8 m raised beach extends from near the present sea level up to *c.* 8 m a.m.s.l. A complex sequence of rhyolitic ignimbrites, andesitic agglomerates and tuffs of the St John's Rhyolite Formation are well exposed in the eastern part of the site. These rocks provide crucial evidence of the changing environment (from acidic to intermediate calc-alkaline, extrusive volcanic activity) and of eruptions in both terrestrial and aqueous settings during the accumulation of the *Jersey Volcanic Group*. This could lead, in turn, to a clearer understanding of the evolution of the ancient island arc during the Cadomian Orogeny. Despite the complexity of the succession, and apparent discrepancies between the descriptions of the sequence within the published research, the site would provide a fruitful opportunity for further detailed investigation of the evolution of the volcanic pile. This is because the exposures are less difficult and dangerous to access than those within the Bouley Rhyolite Formation at the adjacent Giffard Bay site.

Assessment of Site: Current Site Usage	
Community	The shoreline is used by locals and tourists for general outdoor recreation purposes. The clifftop immediately above the central and western cliff sections is the site of a retirement home and a small number of private houses.
Education	This is the only section (we think) in Jersey with exposed sediments related to an ancient lagoonal environment, and therefore it may have some interest for palaeoenvironmental dating or taxonomy specialists.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	As evidenced by the netting, the site is undergoing erosion by weathering and wave action.
Potential use	This site could be used as part of a geotrail, although interest in the site would most likely be limited to specialists in volcanic rocks and Quaternary geology.

Site Photos

Photo 1: Section in the western exposure at Bonne Nuit Bay. A cemented pebble unit, interpreted as being part of the 8 m raised beach, can be seen at the base of the section, overlain by loessic head, beneath coarser-grained head with angular clasts. BGS © UKRI 2020.

Photo 2: Panoramic view of the central and eastern section below the retirement home. The protective netting can be seen in the right part of the image; unfortunately, it causes fine-grained material to be deposited on the exposure, thus obscuring all features and structures in this part of the section. The left-hand, eastern side of the image clearly shows head units, dipping to the east away from the central axis of the palaeofan structure. Each unit likely records an individual fan-forming event. To the west of the netting, this sequence is reflected, with head units dipping to the right and west. BGS © UKRI 2020.

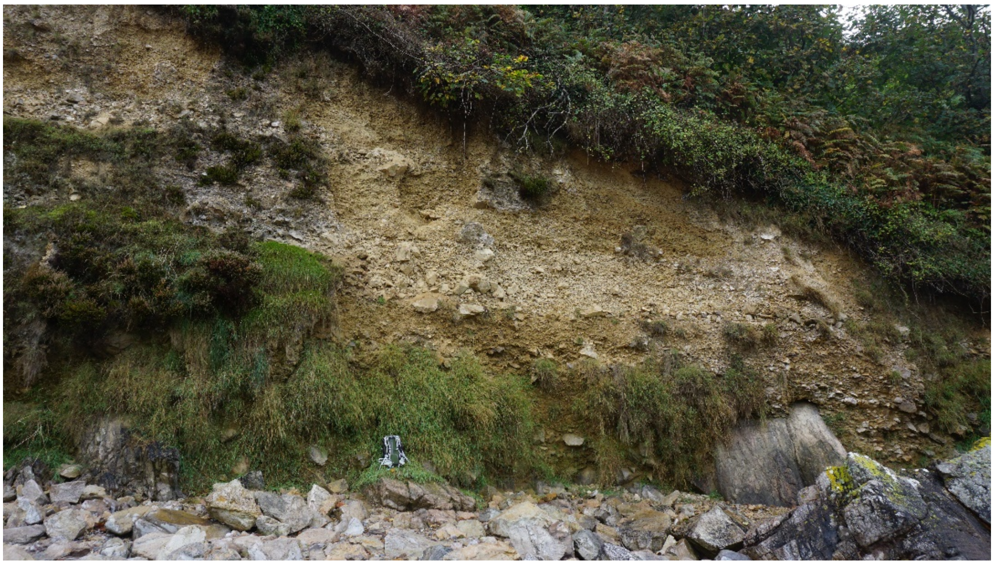


Photo 3: Image showing poorly stratified head units at the western end of the central exposure, to the west of the coastal defence netting. The head is relatively well cemented and well consolidated, and it is clast-rich, with angular clasts varying from boulders (*c.* 50 cm long axis) down to medium-grade gravel. BGS © UKRI 2020.

Photo 4: View of the eastern section in Bonne Nuit Bay, where basal head units can be seen dipping to the east, away from the central axis of the palaeofan. These units appear to have erosional basal contacts, indicating energetic depositional environments. Towards the upper part of this section, a thin, sub-20-cm-thick band of grey silty sandy material can be seen. This has been interpreted as having formed in aqueous conditions. This is in turn overlain by further head units. The head in this section in general contains somewhat finer-grained material than the head exposed to the west of the defensive netting, most likely reflecting the distance from the source of the head material. BGS © UKRI 2020.

Photo 5: Close-up of the fine-grained, grey, silty sandy unit in the eastern Bonne Nuit section. Clearly visible are flame structures, which are related to the loading of this unit from above when it was still waterlogged. This is interpreted here as loading by the progressive deposition of head material into this aqueous environment. BGS © UKRI 2020.

Photo 6: Close-up of the rounded, clast-supported pebble gravel of the 8 m raised beach, beneath head at the eastern end of the site. BGS © UKRI 2020.

Photo 7: Stratified cobbly head deposits in the cliff section, backing the middle part of the Bonne Nuit site immediately to the east of the netted area of the cliffs. Note the erosional base of the upper cobbly head deposit, *c.* 1 m above the figure. BGS © UKRI 2020.

Photo 8: Bedrock exposures in the St John's Rhyolite Formation at the eastern end of the Bonne Nuit site, looking east towards La Crête fort. The light-coloured rock is the Frémont Ignimbrite, which forms the headland beneath the fort. The darker rocks beneath it are part of the outcrop of the Bonne Nuit Agglomerate and the Bonne Nuit Andesite of Bishop and Bisson (1989). BGS © UKRI 2020.

Photo 9: Bonne Nuit Bay, looking westwards from the eastern end of the site. The Andesitic Agglomerate and the Bonne Nuit Ignimbrite are exposed in the foreshore reefs in the middle of the image; a more mixed assemblage of rocks, including ignimbrite, sandstone and andesitic lava, occurs in the foreshore exposures in the middle distance. These exposures occur seaward of the main exposures in the Quaternary sequence in the cliffs. The rocks are partially covered by iron-cemented gravel, interpreted as a Pleistocene beach deposit, occurring close to the present-day m.s.l. Much of the Quaternary sequence in the cliffs in the western part of the site is obscured by coastal defence netting and gabions in front of the flats (top right part of the image). BGS © UKRI 2020.

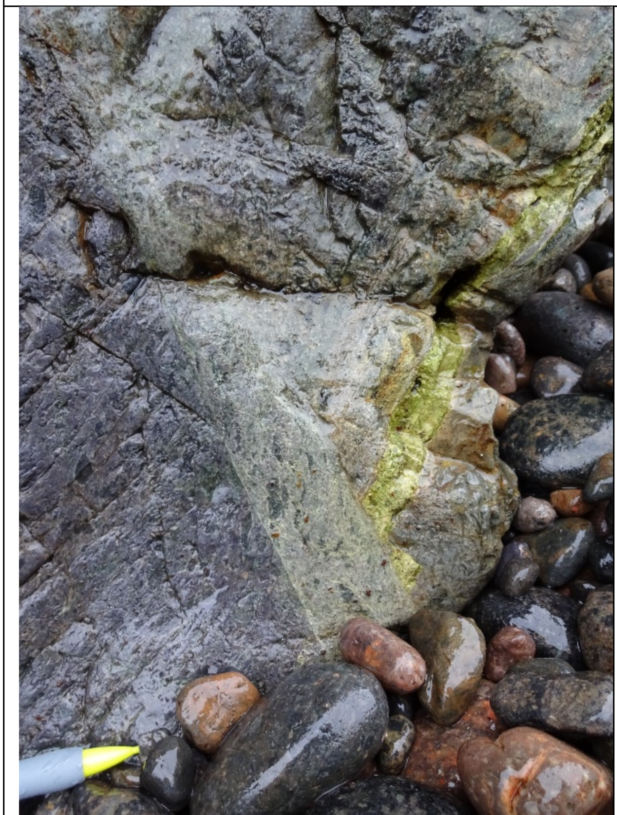


Photo 10: A peperitic margin (light grey) within the Bonne Nuit Agglomerate at the eastern end of the Bonne Nuit site. BGS © UKRI 2020.

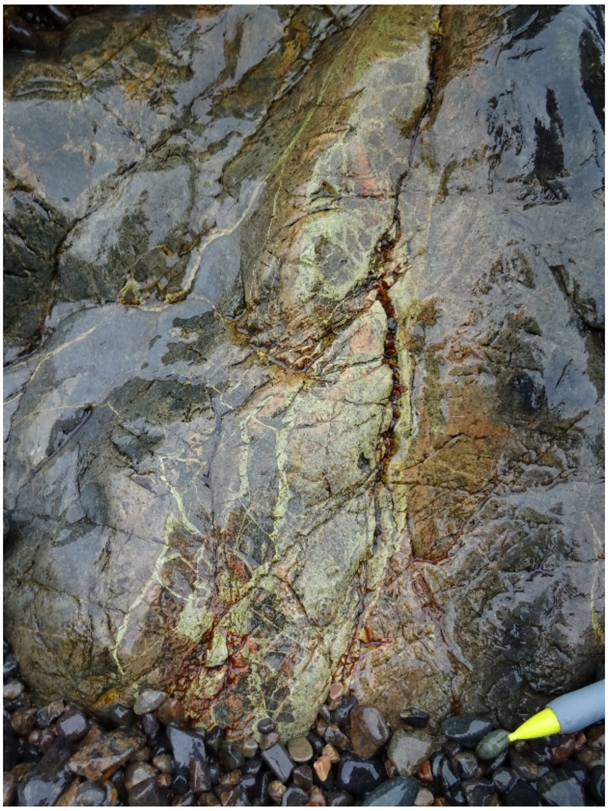


Photo 11: A peperitic margin within the Bonne Nuit Andesite in the eastern part of the Bonne Nuit site. BGS © UKRI 2020.

 **Photo 12:** The Bonne Nuit Tuff, with euhedral and subhedral feldspar crystals in a grey microcrystalline groundmass. BGS © UKRI 2020.	 **Photo 13:** Andesitic agglomerate from the eastern part of Bonne Nuit Bay. BGS © UKRI 2020.

Photo 13: A volcanic bomb within the Bonne Nuit Agglomerate in the eastern part of the Bonne Nuit site. BGS © UKRI 2020.

Photo 14: Xenoliths, possibly of siltstone, within the Bonne Nuit siltstone, which is within the Bonne Nuit Agglomerate. BGS © UKRI 2020.

Photo 15: Eutaxitic texture displayed by flattened and streaked pumice lapilli in the Bonne Nuit Ignimbrite**.** BGS © UKRI 2020.

Photo 16: Possible cross-bedding within a body of sandstone from the ‘mixed sequence’ of rocks, in foreshore exposures in the middle part of the Bonne Nuit site. BGS © UKRI 2020.

Photo 17: Near-vertical layering within the ‘Bonne Nuit Ignimbrite’ in foreshore exposures in the middle part of the site. BGS © UKRI 2020.

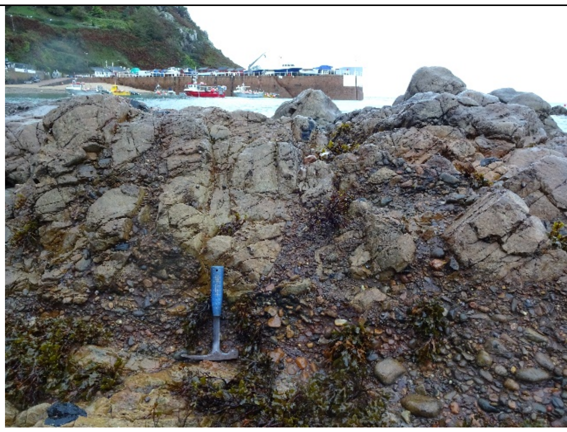
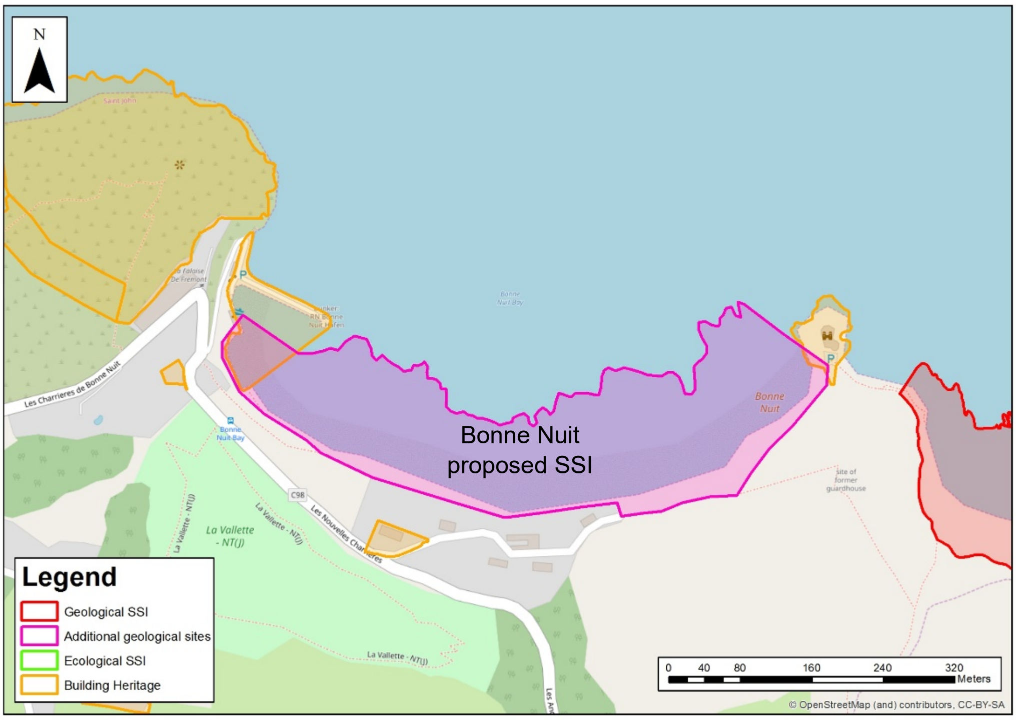


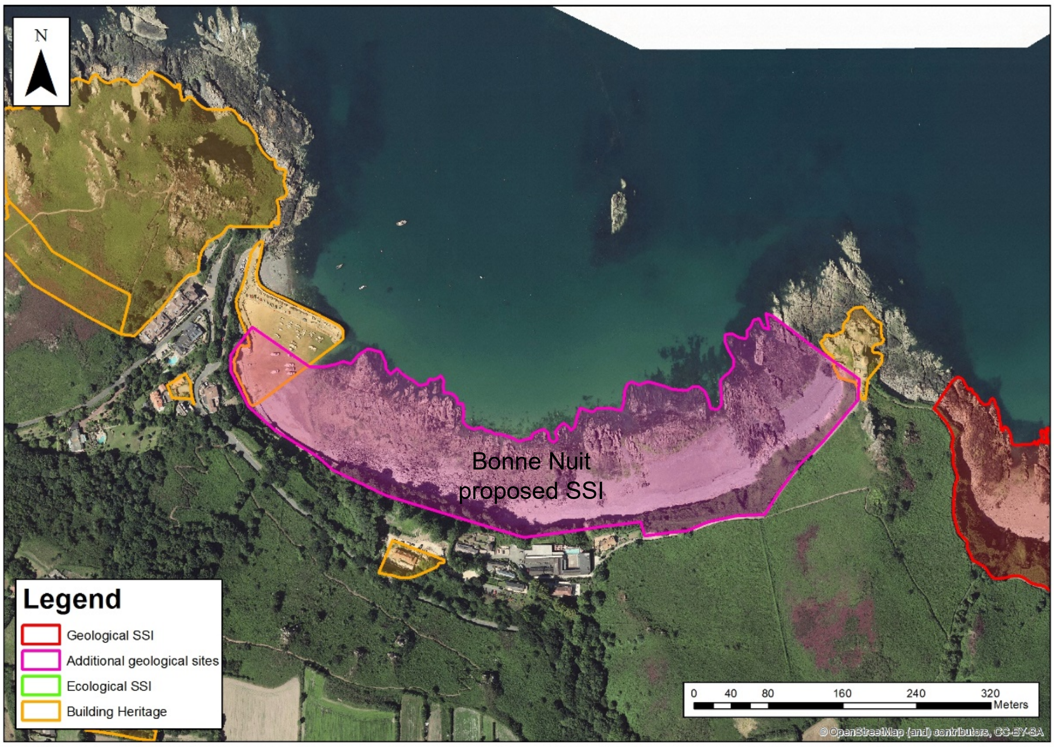
Photo 18: Iron-cemented Pleistocene beach gravel, probably equivalent to the ‘submerged beach’ of Mourant (1933), plastered against the Bonne Nuit Ignimbrite in foreshore exposures from the middle part of the site. BGS © UKRI 2020.

Map of the site boundary on a topographic base



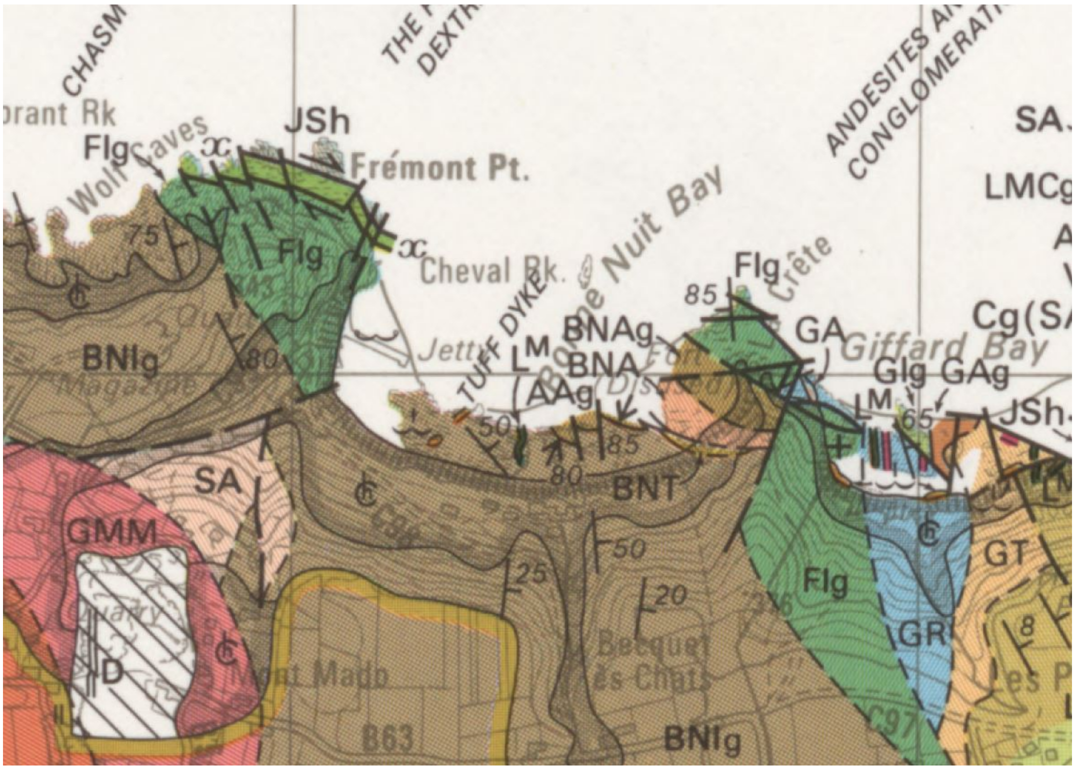
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



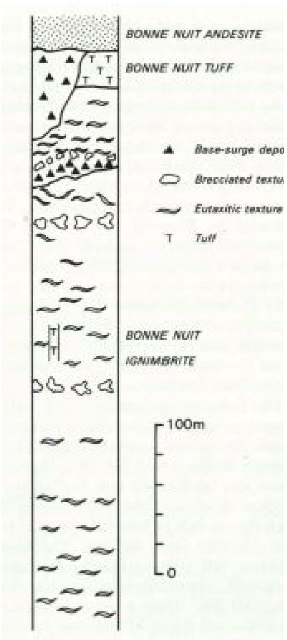
Imagery ©2020 Government of Jersey.

Published geological map of the site



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km.

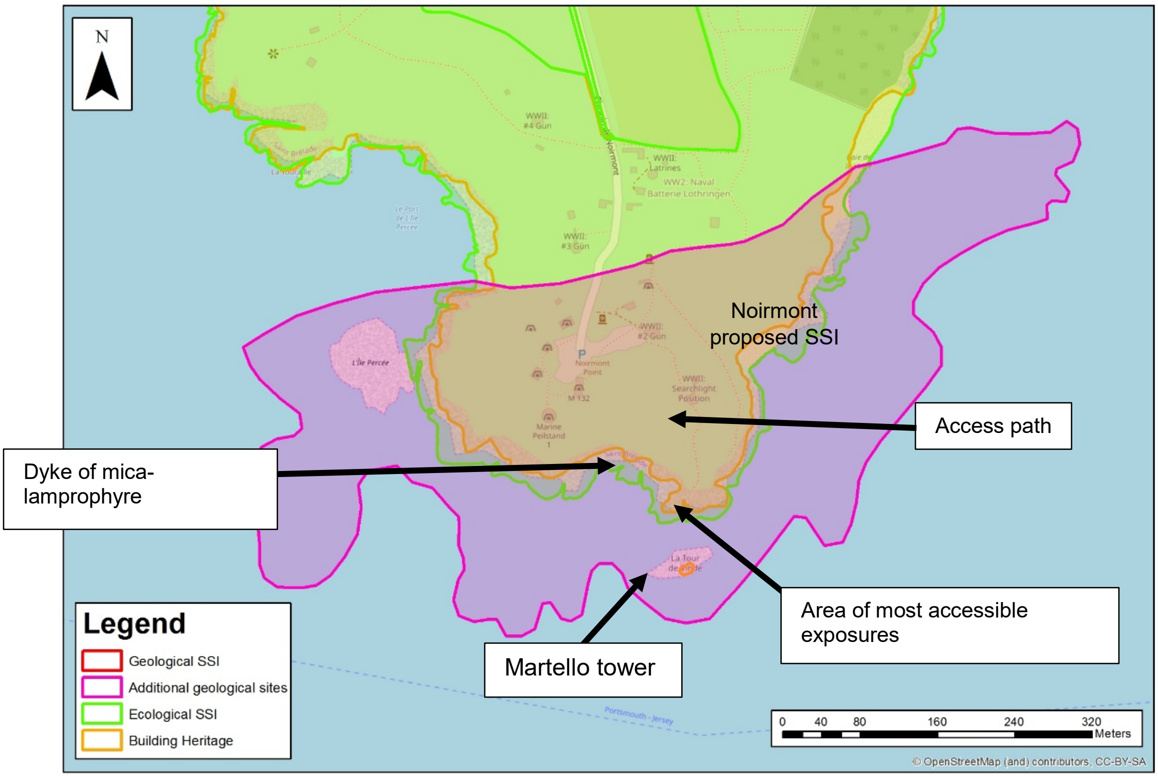
Reconstructed section through the rocks of the St John's Rhyolite Formation exposed at the eastern end of Bonne Nuit Bay (reproduced from Bishop and Bisson, 1989, figure 8).



8.6 SITE NAME: NOIRMONT, PROPOSED SSI

Site Information:	
The site is a craggy headland at Noirmont on the south coast of Jersey. A wide range of intrusive igneous rocks are the main features of interest. The bedrock is primarily *Corbière granite*, the most extensive component of the *South-west igneous complex*. The site includes excellent exposures of typical *Corbière granite*, dolerite dykes of the *Jersey Main Dyke Swarm* and a late mica-lamprophyre dyke. The site also presents exposures of Quaternary deposits.	
National Grid Reference: Mid-point: 37597, 63424 West end: 37529, 63463 East end: 37673, 63508	**Site Type:** Natural exposure
Site Ownership: To be confirmed	**Current Use:** Open country, coastal
Field Surveyors: M Gillespie and R Kendall	**Current Geological Designations:** None
Date Visited: 15 October 2019	**Other Known Designations:** The site area coincides with part of an Ecological SSI (Noirmont) and a Building Heritage site (German Occupation Site: Naval Coastal Artillery Battery 'Lothringen'). The site encloses another Building Heritage site (Noirmont Tower). The site also sits within Jersey National Park.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** *South-west igneous complex* (Corbière granite)
Rock Types: Granite	
Age: Ediacaran Period (late Precambrian)	**Formation:** Jersey Main Dyke Swarm
Rock Types: Basalt/dolerite	
Age: Not known	**Formation:** Unnamed swarm of late lamprophyre dykes
Rock Types: Mica-lamprophyre	
Age: Quaternary	**Formation:** Unnamed deposit
Rock Types: Head (poorly sorted and weakly stratified deposit containing angular blocks of local bedrock)	

Site Description:

Introduction

Noirmont, a craggy headland on the south coast of Jersey, is an excellent place to see typical *Corbière granite* (the most extensive component of the *South-west igneous complex*) and a range of features that provide insight into the inner workings of a granite magma chamber, including miarolytic cavities and cross-cutting sheets of aplite. The site is also a good place to see typical basaltic dykes of the *Jersey Main Dyke Swarm* and a mica-lamprophyre dyke.

The most readily accessible exposures, which include examples of all the main features of interest, are at the southernmost part of Noirmont Point, on the intertidal platform north of the Martello tower (Photo 1). Access to this area is via a moderately steep, largely unmaintained footpath that starts next to a WW2 gun emplacement at the east end of the parking area and descends the spine of the headland towards the shore and the Martello tower (La Tour de Vinde, or Noirmont Tower). The full range of geological features can only be appreciated fully in the rocky platform of the intertidal zone, which requires visitors to walk over rough, rocky ground that may be slippery and in places can involve mild scrambling.

Bedrock Units

South-west igneous complex

The *South-west igneous complex* is one of three major intrusion complexes in Jersey. Three main components are apparently distributed in a concentric or 'bullseye' pattern (IGS, 1982): *Corbière granite*, which is by far the most extensive and forms around 80% of the onshore outcrop, comprises the outer zone; *La Moye granite*, which underlies a narrow belt roughly 250 m wide, forms the middle zone; and *St Brelade's granite* forms the small central zone. This pattern indicates that the *South-west igneous complex* is a single, concentrically zoned pluton, and in this respect, it is similar to the *North-west igneous complex* and distinct from the *South-east igneous complex*. The pluton apparently consists almost entirely of granite (no mappable occurrences of mafic rock or rocks formed by the mingling of basic and siliceous magmas have been recorded), and in this respect it differs from both the *North-west igneous complex* and the *South-east igneous complex*.

The geometry of the bullseye pattern suggests that around half of the outcrop of the *South-west igneous complex* is on mainland Jersey, with the other half lying offshore; on this basis, the outcrop of the whole pluton would be around 8 x 5 km. However, granitic rocks crop out on the seafloor for a considerable distance to the south of the south-west Jersey coast (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the south of the *South-west igneous complex* (Figure 1). The offshore outcrop of intrusive igneous rocks actually extends unbroken along the entire south coast of Jersey, suggesting that the *South-west igneous complex* and *South-east igneous complex* are part of the same large outcrop of intrusive igneous rocks (Figure 1).

A U-Pb zircon age of *c.* 580 Ma for a sample of *Corbière granite* from a disused quarry north of La Cotte, on the east side of Ouaisné (Miller *et al*., 2001), confirms that the *South-west igneous complex* was emplaced during the Ediacaran Period (late Precambrian). As such, it was probably a late-stage feature of the Cadomian Orogeny. It is around 100 million years older than the *North-west igneous complex*.

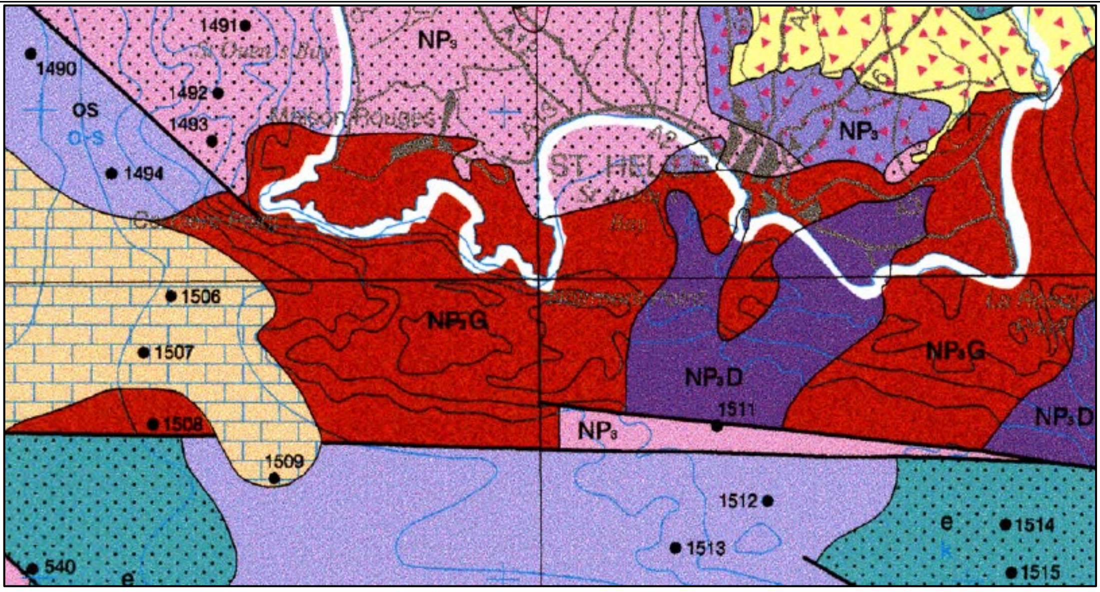


Figure 1. Map of onshore and offshore bedrock geology around the southern half of Jersey (coastline in white) showing the apparent offshore continuation of the *South-west igneous complex* and *South-east igneous complex*. From BGS (2000).

Jersey Main Dyke Swarm

The *Jersey Main Dyke Swarm* is the name assigned by Lees (1986) to the obvious concentration of dykes that crop out within the E–W-trending area of ground underlain by the two main igneous complexes in south Jersey. The dykes typically are steeply dipping, and most are less than 1 m wide; good coastal exposures reveal that they can account for around 10% of the outcrop locally. The swarm is particularly well exposed, and particularly abundant, in the extensive intertidal reef to the west and east of Le Croc in south-east Jersey.

The dykes display strong preferred orientations: E–W in the *South-west igneous complex* and NE–SW in the *South-east igneous complex*. A small proportion of dykes have a broadly N–S trend; these dykes must have opened in a stress regime different from that of the dykes forming the main part of the swarm, indicating that the swarm as a whole had a multistage emplacement history.

Dykes of basic (i.e., basalt and dolerite) composition predominate, but Lees (1986) noted that the dykes cutting the *South-west igneous complex* are mainly dolerite, whereas those cutting the *South-east igneous complex* display a broader range of compositions, including dolerite, microdiorite, lamprophyre and rhyolite (or microgranite). Where they occur together, for example, in exposures on the foreshore at Mont Orgueil, the basic (doleritic) dykes often cut the siliceous dykes. Many dykes are porphyritic; small phenocrysts of plagioclase and ferromagnesian minerals predominate in dykes of basic composition, while phenocrysts of quartz and feldspar occur in siliceous examples. Some dykes are composite, containing both basic and siliceous components; in such cases, basic margins and siliceous centres are common.

The dykes were emplaced during and shortly after the later stages of assembly of the two main igneous complexes in south Jersey (Lees, 1986). This indicates that they formed in the Ediacaran Period (late Precambrian), as a late-stage feature of the Cadomian Orogeny. Based on whole-rock chemical analyses, Lees (1986) described the swarm as having a calc-alkaline character of a potassium-rich ('high-K') type, typical of magmas generated above active subduction zones.

Dykes of similar lithologies, and often with similar trends, occur in other parts of Jersey, although they are relatively rare; many are probably genetically related to the *Jersey Main Dyke Swarm*.

Late lamprophyre dykes

Lamprophyre is a relatively rare form of igneous rock that crystallises from small batches of ultrapotassic magma sourced directly from the mantle. Hornblende-bearing lamprophyre is a minor component of the *Jersey Main Dyke Swarm* (and of contemporaneous intrusions that are technically not part of the swarm). Younger dykes of mica-bearing lamprophyre are much more common and have been recorded in many parts of Jersey (e.g., Smith, 1933, 1935). Most are less than 2 m thick (occasionally they reach 3 m), subvertical and broadly N–S trending (mainly in the sector between NNW–SSE and NNE–SSW). These late lamprophyre dykes have not been dated but have been observed cutting all the main bedrock units in Jersey, including the Ordovician *North-west igneous complex* and the *Rozel Conglomerate Formation*. They appear therefore to be the youngest bedrock features in Jersey, and they may be related to the Variscan (also known as the Hercynian) Orogeny, which produced abundant magmatism in south-west England and north-west France during the Devonian and Carboniferous periods. Thin sections of the Jersey examples typically reveal phenocrysts of olivine (always pseudomorphed by carbonate and serpentine), pyroxene and mica (biotite) in a fine-grained and variably altered groundmass of alkali feldspar, ferromagnesian silicate minerals and opaque oxide (e.g., Smith, 1935; Bishop and Bisson, 1989); lamprophyres with this mineral composition are called minettes.

Bedrock Features

Nearly all of the bedrock at Noirmont is *Corbière granite*. In most respects, the granite here is typical of *Corbière granite* elsewhere in Jersey: it is coarse-grained, uniform and lacking phenocrysts, with a strong pinkish-orange colour that in detail consists of brick-red alkali feldspar, pale orange to white plagioclase feldspar and grey to white quartz, with a small proportion of black biotite mica (Photo 2). Like all other intrusions in Jersey, the rock has not been affected by strong regional-scale deformation, so the granite lacks a pervasive tectonic fabric and the rock texture is largely as it was when it crystallised. However, the outcrop of *Corbière granite* at Noirmont is cut by a variably dense network of thin, dark fractures, some of which are associated with weak brecciation and mm-scale displacements (Photo 2). In places, the largest of these form sub-parallel sets that are effectively a 'spaced fracture cleavage' (Photo 3). The dark mineralisation is probably mainly chlorite, formed when hot water moved through the fractures and reacted with minerals in the granite. These features indicate that this part of the *Corbière granite* has been weakly deformed under conditions that were cool enough to produce numerous brittle fractures but warm enough to produce new 'hydrothermal' minerals, such as chlorite. The fractures do not affect cross-cutting dykes of the *Jersey Main Dyke Swarm*, so the deformation must have happened shortly after the granite crystallised, perhaps when a younger component of the *South-west igneous complex* was emplaced forcefully.

Circular to elongate weathering pits have formed where the brittle fractures described above intersect near-horizontal surfaces in the granite outcrop (Photo 3). The fractures represent lines of weakness in the rock, so on near-horizontal surfaces (where water can accumulate), they have been weathered and eroded in a selective manner to produce weathering pits with a range of shapes.

Miarolytic cavities (voids lined by euhedral crystals), and veins with a similar character (i.e., unfilled, and lined by perfectly formed crystals of quartz and feldspar), are common in some parts of the outcrop; most are mm-scale, but the largest are on the order of 10 cm. These features indicate that the magma was relatively water-rich, and that water or water vapour become concentrated in, and then separated from, the magma as it crystallised. A fluid phase cannot separate from magma if the confining pressure is too great (i.e., if the chamber is too deep in the crust), so features like these provide evidence that the magma was both relatively fluid rich and emplaced at a relatively shallow depth.

Thin sheets of brick-red to pink microgranite (sometimes referred to as felsite or aplite) also cut the granite outcrop at Noirmont. These may be a very late-stage product of the magmatism associated with the *Corbière granite*, or they may be related to a younger component of the *South-west igneous complex*.

Several dykes of dark grey dolerite and basalt cut the granite outcrop (Photo 4). The dykes, which are subvertical, up to 2 m wide and trend roughly E–W, almost certainly belong to the *Jersey Main Dyke Swarm*. The dykes have well-developed chilled margins of non-porphyritic basalt, while their centres consist of coarser-grained dolerite in which small, white phenocrysts of plagioclase can usually be seen (Photo 5). Most contacts between the dykes and host granite are intact, but some have been reactivated (deformed) by later tectonic activity.

A mica-lamprophyre (minette) dyke cuts both the granite and a dyke of the *Jersey Main Dyke Swarm* on the west side of the intertidal outcrop at Noirmont (Photo 6). The dyke, which is around 2 m wide, steeply dipping and NNE–SSW-trending, has developed rounded surfaces and has become recessed within a gully in the granite as a result of weathering. Fresh surfaces reveal a grey, medium-grained rock with scattered flakes of fresh black biotite (Photo 7).

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Public road to parking area (Noirmont parking)
Access	A moderately steep, largely unmaintained footpath starts next to a WW2 gun emplacement at the east end of the parking area and descends towards the shore and the Martello tower (La Tour de Vinde, or Noirmont Tower).
Safety of access	The path down to the intertidal zone may be slippery in places. Some rock can be examined before the intertidal zone is reached, but the full range of geological features can only be appreciated fully on the rocky platform of the intertidal zone.
Safety of exposure(s)	The intertidal zone is formed of rough, rocky ground that is exposed to wind and waves. The ground here may be slippery at times, and mild scrambling is required to access some parts.
Current condition	The exposures are generally clean and sound. Barnacles, limpets and algae coat the rock to varying degrees, but there is little seaweed.
Current conflicting activities	None known
Restricting conditions	The bedrock exposures are mainly in the intertidal zone and will be inaccessible at times. The Quaternary sections, although they lie above the normal high-tide mark, may be difficult to access when the tide is in.
Nature of exposure(s)	An intertidal rock platform presents a large area of clean, well-exposed bedrock. The Quaternary deposits are exposed in the back walls of small landslips on vegetated cliffs above the intertidal outcrop.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Batterie Lothingen, incorporating the prominent 'Marine Peilstand 1' tower, is part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall (HER Number 0100247; Listed building BR0247). La Tour de Vinde, or Noirmont Tower, is a Martello-type tower built in 1811 that sits on the southernmost outcrop of the site (HER Number 0100085; Listed building BR0085). Bevel-ended tool (HER Number 0100437). Noirmont artefacts (HER Number 0100438).
Aesthetic landscape	Noirmont provides extensive views across the south coast of Jersey. The Martello tower is a popular subject in photographs. The intertidal zone is an impressively craggy section of coast.
History of Earth science	No known associations
Economic geology	No known associations

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Regional	Good	Descriptions	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The site is primarily of interest because of the range of intrusive igneous rocks, and associated minerals, textures and relationships, which can be examined within a small area in exposures of excellent quality. It is one of the most accessible places in Jersey that contains clean, extensive outcrops of *Corbière granite*, which display good examples of late-stage magmatic features (miarolytic cavities and microgranite sheets), the effects of post-magmatic deformation and weathering pits. The site is also an excellent place to examine representative examples of both of the main phases of minor intrusions in Jersey.

Assessment of Site: Current Site Usage	
Community	The modern beach is used for typical beach-related recreational activities.
Education	None known

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust. The Quaternary cliff sections are largely above high tide but prone to weathering/erosion.
Potential use	The site is aesthetically impressive and contains a range of geological, ecological and historical features; as such, it would be useful for school trips, higher education and special interest groups.

Site Photos:

Photo 1: Looking north-west from the Martello tower at the southern limit of Noirmont, along the intertidal zone formed of *Corbière granite*. Orange head is exposed at the back of small landslips formed in the vegetated cliff behind the rocky shore. The 'Marine Peilstand 1' tower is on the skyline. BGS © UKRI 2020.

Photo 2: Typical Corbière granite at Noirmont cut by a network of thin, dark veins and deformation bands. Pen for scale. BGS © UKRI 2020.

Photo 3: Round weathering pits developed along zones of closely spaced and intersecting microfractures in Corbière granite. Pen for scale. BGS © UKRI 2020.

Photo 4: An E–W-trending dyke of grey dolerite and basalt of the Jersey Main Dyke Swarm cutting Corbière granite on the intertidal platform at Noirmont Point. BGS © UKRI 2020.

Photo 5: A chilled margin developed in the dyke shown in Photo 4. The interior of the dyke, on the right, is coarser-grained and contains small, pale phenocrysts. The chilled margin (beneath the finger) is finer-grained and lacks phenocrysts. BGS © UKRI 2020.

Photo 6: A N–S-trending dyke of dark grey mica-lamprophyre cutting orange Corbière granite in the intertidal zone at Noirmont Point. The lamprophyre dyke is preferentially weathering around its joints and developing 'spheroidal weathering'. Figure for scale. BGS © UKRI 2020.

Photo 7: Close-up of the mica-lamprophyre dyke shown in Photo 6. The small dark specks scattered throughout the rock are fresh euhedral crystals of biotite mica. Pen for scale. BGS © UKRI 2020.

Photo 8: Orange head exposed in vegetated cliffs above the rocky intertidal zone (formed of Corbière granite) at Noirmont Point. The vegetated cliff is around 10 m high. BGS © UKRI 2020.

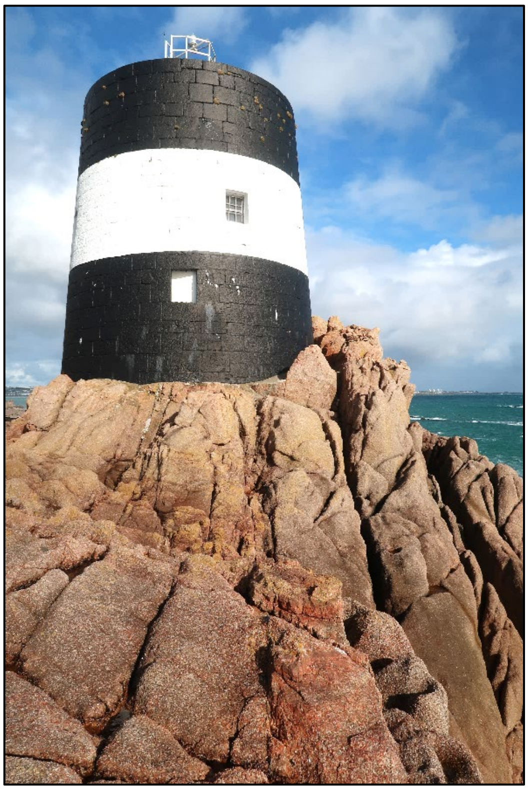
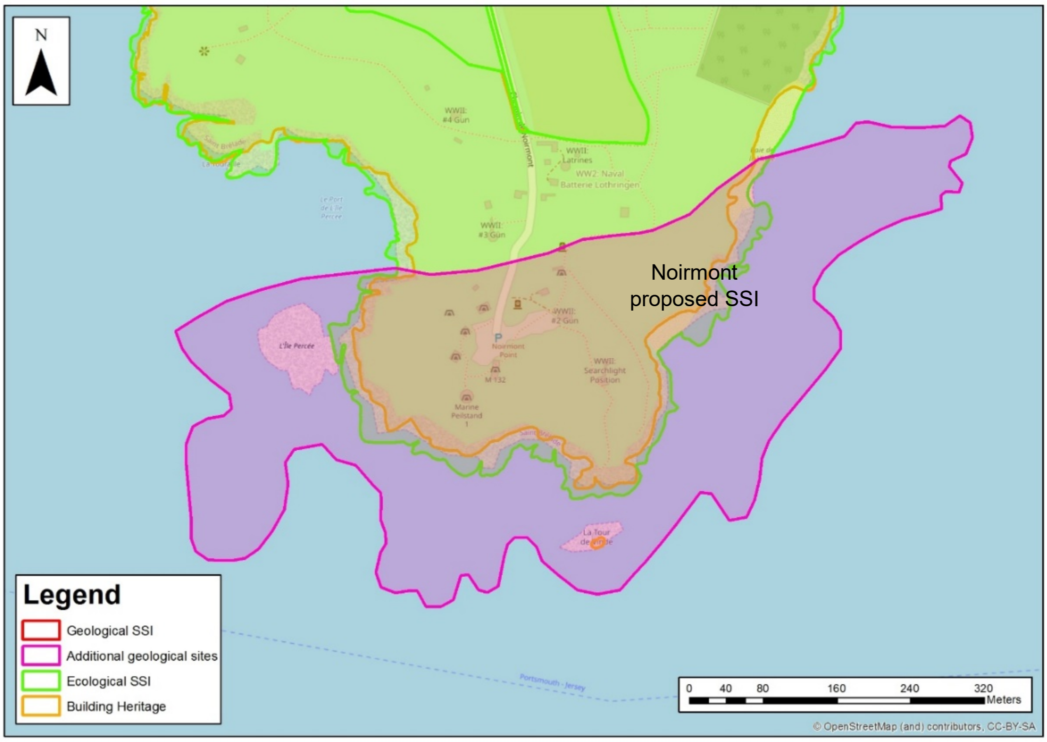


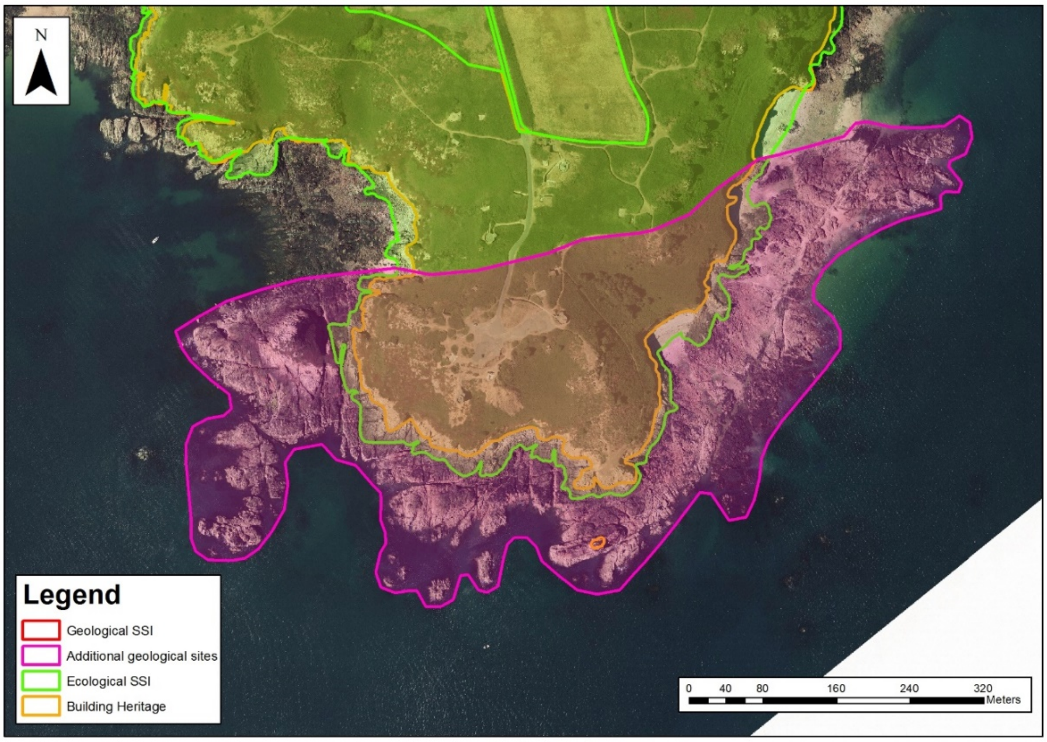
Photo 9: La Tour de la Vinde, a well-preserved Martello tower that was built on an elevated platform of eroded Corbière granite at the southern limit of the Noirmont site. BGS © UKRI 2020.

Map of the site boundary on a topographic base



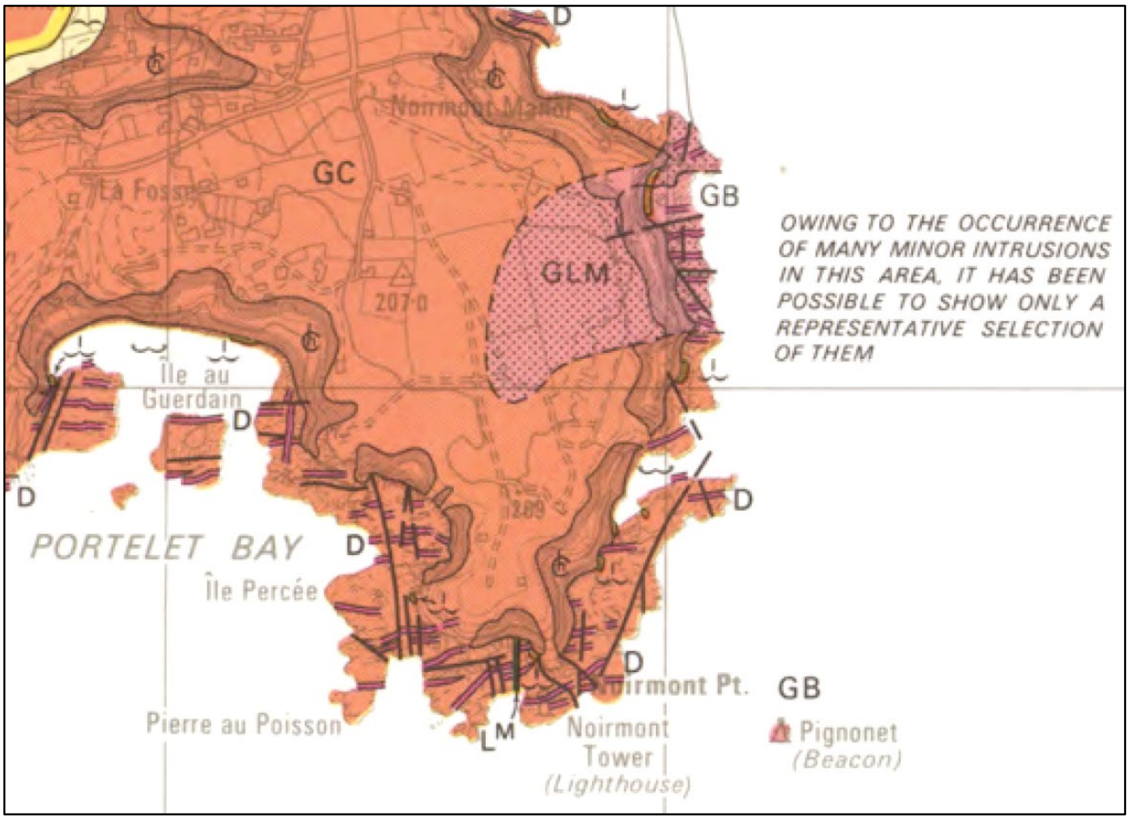
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site



Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

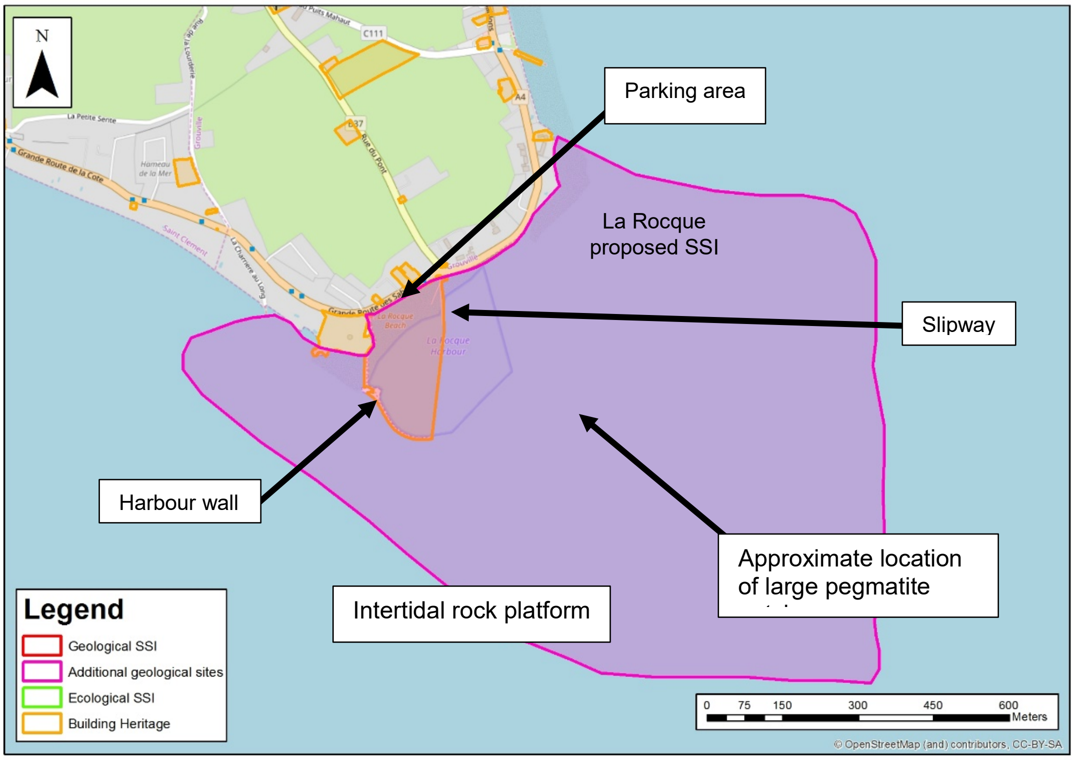
8.7 SITE NAME: LA ROCQUE, PROPOSED SSI

Site Information:

The site encompasses part of the intertidal zone around La Rocque Harbour, at the south-east extremity of mainland Jersey. The bedrock is *La Rocque granite* of the *South-east igneous complex*. The site includes perhaps the best exposures of *La Rocque granite* (the most extensive, and youngest, major component of the *South-east igneous complex*) in any of the Jersey geodiversity sites, and it includes some of the best examples in Jersey of features found in fluid-rich magmas (coarse pegmatitic granite and miarolytic cavities). Slipways, breakwaters and walls within the site present a good display of Jersey igneous rocks used as building stones. The site also provides an excellent view over the largest intertidal rock platform (or reef) on the Jersey coast.

National Grid Reference: Mid-point: 47878, 63130 West end: 47036, 63220 East end: 48436, 63082	**Site Type:** Natural exposure and manmade artefact
Site Ownership: To be confirmed	**Current Use:** Open country, coastal
Field Surveyors: M Gillespie and R Kendall	**Current Geological Designations:** None
Date Visited: 15 October 2019	**Other Known Designations:** The site includes a Building Heritage site (La Rocque Harbour).

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** *South-east igneous complex* (La Rocque granite)
Rock Types: Granite, pegmatitic granite	
Age: Ediacaran Period (late Precambrian)	**Formation:** Various
Rock Types: Granite, pegmatite, aplite, diorite and volcanic rock (used as building stones)	

Site Description:

Introduction

The La Rocque site is one of the best places in Jersey to examine exposures of *La Rocque granite*, the most extensive and youngest main component of the *South-east igneous complex*. Here, this granite includes superb examples of late- to post-magmatic features commonly associated with fluid-rich magmas, including *pegmatite* and *miarolytic cavities*. The site also provides a good display of Jersey igneous rocks used as building stones and excellent views over the largest intertidal rock platform (or reef) on the Jersey coast. Exposures beside the harbour wall are easily accessed by a short walk, but much of the site lies in the intertidal zone; here, access to the best exposures requires walking on rough, rocky and potentially slippery ground.

Bedrock Units

South-east igneous complex

Several lithologically distinct components have been mapped within the *South-east igneous complex* (Figure 1), including large (km-scale) masses of basic rock ('diorite and gabbro') and three main variants of granite (IGS, 1982). The earliest component of the *South-east igneous complex* comprises dark grey diorite, grading locally to gabbro. This facies forms several discrete, km-scale outcrops. The largest outcrop underlies the intertidal reef off La Grève d'Azette and extends inland as far as Grouville; another substantial (km-scale) mass forms a cluster of reefs to the south of Seymour Tower, at the south-east extremity of the extensive reef lying south of La Rocque. Primary igneous layering in diorite and gabbro is preserved in several intertidal exposures, including exposures near La Grève d'Azette, at Le Nez and in the skerries south of Seymour Tower. The consistent character and orientation of the layering, which generally dips towards the north-east at around 60–70^0 (*c.* 30^0 near Seymour Tower), suggests that these widely separated outcrops were once part of the same large body of layered rocks, which was perhaps the earliest expression of the *South-east igneous complex*. Evidence for a dynamic magma environment, in the form of intimately associated and broadly contemporaneous but compositionally distinct basic, intermediate and siliceous rocks, is well displayed in several localities. Notable examples include the exposures between Le Croc and La Motte, at Havre des Pas Pier and at Elizabeth Castle (where the siliceous component is part of a km-scale mass sometimes referred to as the *Fort Regent Granophyre* [e.g., Bishop *et al*., 2003]). Injections of basic and siliceous magma may have destroyed early layering in parts of the magma chamber, and the early body of layered rocks may have been tilted and dismembered when large masses of granite magma (forming the three main granite variants of the *South-east igneous complex*) were subsequently emplaced.

The strongly porphyritic *Dicq granite* is the least extensive of the three mapped variants of granite in the *South-east igneous complex*; its outcrop is restricted mainly to a portion of the intertidal zone south of Grève d'Azette and near Havre des Pas, where the magma has cut and locally mingled with the early dioritic facies. A further small (*c.* 100 x 100 m) outcrop of *Dicq granite* is mapped *c.* 1.2 km north-east of Le Dicq. The essentially non-porphyritic

Longueville granite underlies a significantly larger area of ground beneath the south-east part of St Helier and to the north of the largest body of dioritic rock; however, exposure is very poor over most of the outcrop. *Longueville granite* and *Dicq granite* are probably broadly contemporaneous (see the description for the Dicq to Havre des Pas geodiversity site). *La Rocque granite* (called 'Le Hocq granite' by Lees [1986] and 'Le Hocq–La Rocque–Gorey granite' by Bishop *et al*. [2003]) is by far the most extensive granite component of the *South-east igneous complex*, at least onshore. It forms much of the intertidal reef in St Clement's Bay and crops out on the mainland north of there, as far as Mont Orgueil. Cross-cutting relationships with dykes in the *Jersey Main Dyke Swarm*, which are well displayed in intertidal exposures near La Grève d'Azette, indicate that *La Rocque granite* is also the youngest of the main granite components in the *South-east igneous complex* (IGS, 1982).

Unlike the other two large intrusion complexes in Jersey, the main components of the *South-east igneous complex* are not arranged in a pattern of concentric zones; instead, they form irregularly distributed and irregularly shaped, discrete, km-scale masses dominated by either diorite and gabbro or granite (IGS, 1982). The onshore outcrop of the *South-east igneous complex* (including the intertidal reefs) is at least 10 x 7 km in extent. However, granitic and dioritic rocks crop out on the seafloor for a considerable distance to the south, west and east of the south-east Jersey coast (BGS, 2000), suggesting that the onshore outcrop of the *South-east igneous complex* is just a small part of a much larger intrusive complex (Figure 6). Indeed, the offshore outcrop of intrusive igneous rocks extends unbroken along the entire south coast of Jersey, suggesting that the *South-west igneous complex* and *South-east igneous complex* are part of the same large outcrop of intrusive igneous rocks (Figure 6).

There are no U-Pb zircon ages reported for the *South-east igneous complex*. Instead, a range of ages between *c.* 583 and 527 Ma that are based on the K-Ar isotope system have been reported (Adams, 1967; D'Lemos *et al*., 1992). The K-Ar system is prone to resetting during rock alteration events, so generally it does not produce accurate dates for the crystallisation of coarse-grained igneous rocks; consequently, the results should not be compared directly with U-Pb zircon ages. Similarities in the characteristics of cross-cutting dykes (*Jersey Main Dyke Swarm*), and the fact that intrusive plutonic rocks form an unbroken outcrop offshore between the south-west and south-east extremities of Jersey (Figure 6), suggest that the *South-west igneous complex* and *South-east igneous complex* are broadly contemporaneous. Based on this, the *South-east igneous complex* was probably emplaced during the Ediacaran Period, as a late-stage (post-tectonic) feature of the Cadomian Orogeny.

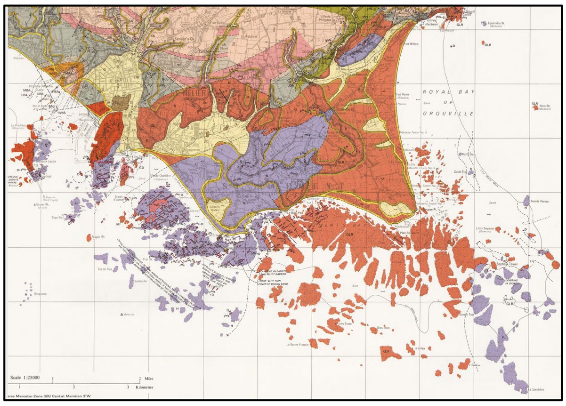


Figure 1. Geological map of the *South-east igneous complex*. From IGS (1982).

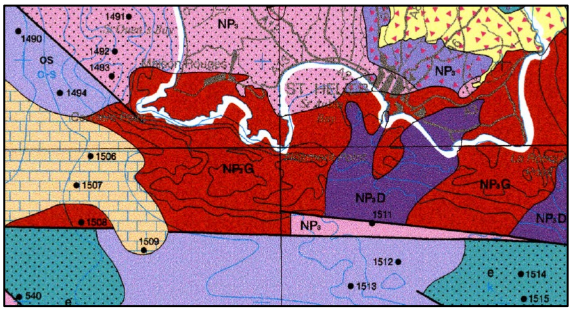


Figure 2. Map of onshore and offshore bedrock geology around the southern half of Jersey (coastline in white) showing the apparent offshore continuation of the *South-west igneous complex* and *South-east igneous complex*. From BGS (2000).

<u>Bedrock Features</u>

The walkway leading to, and along, the harbour wall from the parking area at La Rocque passes through several large, craggy outcrops of granite, which are accessible at all times. These outcrops display examples of all the key features of the site, including typical La

Rocque granite (Photos 1, 3 and 4), aplite sheets and pegmatite patches, although the latter are less spectacular than examples in the intertidal zone.

Typical granite at the La Rocque site is deep orangish-red, lacks phenocrysts and consists of substantial proportions of reddish alkali feldspar, orange plagioclase feldspar and grey to white quartz, with a small proportion of black biotite (Photo 3). The granite here is somewhat coarser-grained than it is at both the west (Le Hocq) and north (Gorey) limits of the *La Rocque granite* outcrop, possibly because the La Rocque site is closer to the centre of the intrusion. The strong reddish colour is probably the result of oxygen-bearing vapour percolating through the cooling or recently crystallised magma, causing finely disseminated iron in the feldspar crystals to oxidise (i.e., 'rust').

The La Rocque site presents excellent examples of several features that can form in magma chambers during and shortly after the final stages of crystallisation, including *pegmatite*, *miarolytic cavities* and *aplite sheets*. As magma crystallises, any chemical elements that are not incorporated in minerals become concentrated in the remaining magma. Through this process, a water-rich 'fluid phase' (sometimes called a vapour phase) commonly accumulates in the last-to-crystallise parts of a magma chamber (often in the top or shallowest part of the chamber), eventually filling isolated 'bubbles' or sheets in the solidifying magma. The fluid phase can still contain the chemical ingredients needed to grow minerals, and the minerals that grow from it are often unusually large because they grow from a low-viscosity fluid rather than magma. The bubbles and sheets crystallise to form patches and veins, respectively, of unusually large crystals; this type of rock is called *pegmatite*. Crystals generally grow from the edge of a bubble or sheet towards the interior, and if the fluid becomes isolated in the magma, the crystals commonly use up the available elements and stop growing before all the space has been filled. For this reason, the last crystals to grow in pegmatite patches and veins are often perfectly formed (euhedral), indicating that they grew unimpeded into a space that was not filled. Voids lined by euhedral crystals are *miarolytic cavities*. A fluid phase cannot separate from magma if the confining pressure is too great (i.e., if the chamber is too deep in the crust), so pegmatite, and miarolytic cavities in particular, are usually taken as evidence that a magma was both relatively fluid rich and emplaced at a relatively shallow depth.

The intertidal outcrops at La Rocque present some of the best examples of pegmatite and miarolytic cavities anywhere. A walk of around 200 m due south from the end of the slipway leads to an area of large exposures in which spectacular examples of pegmatite and miarolytic cavities are scattered conspicuously (Photos 5, 6 and 7). Individual crystals of quartz and feldspar can reach around 10 cm long, and individual patches of pegmatite can be more than 1 m across. Unfortunately, all of the obvious large quartz crystals have been removed by collectors, leaving only hexagonal moulds to indicate that they were once there (Photo 8).

Some parts of the site present good examples of Jersey igneous rocks used as building stones. The angle between the main slipway and a smaller slipway descending from it to the east has been built up with a wide range of igneous rocks from Jersey (Photo 9). These include the following: large blocks of pink to dark pink, coarse granite, with sparse phenocrysts of K-feldspar, in which there are cross-cutting sheets of felsite, patches of pegmatitic rock and schlieren; blocks of pinkish-brown microgranite with phenocrysts of quartz and feldspar ('porphyry') that are also cut by sheets of felsite; smaller blocks of dark purple volcanic rocks, mostly of pyroclastic type; and rare blocks of dark grey diorite. The wall separating the parking area from the beach is formed of blocks of uniform, pink to red granite, which is possibly *Mont Mado granite* from the large Mont Mado Quarry in north Jersey (Photo 10). The slipway at the east end of the parking area is built from setts up to 60 cm long that are formed predominantly of two types of granite – a pale pink, coarse granite with occasional black enclaves, and a dark pink, finer-grained granite (Photo 11); a small proportion of setts are formed of dark grey diorite.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Public road to parking area (La Rocque Harbour parking)
Access	A walkway leading to, and along, the harbour wall from the parking area passes through several large, craggy outcrops of granite, which are accessible at all times and display examples of all the main geological features of the site. However, the best examples of some features can only be examined directly by walking to exposures within the intertidal zone. A slipway leading directly from the parking area provides straightforward (though tide-limited) access to the intertidal zone, and it is the best place at the site to see a good display of Jersey igneous rocks used as building stones.
Safety of access	The harbour wall walkway is elevated but protected on both sides by railings. The intertidal zone can be accessed directly from the walkway by steep stone steps, which are unprotected and at times may be slippery. The slipway provides safe access between the parking area and intertidal zone, although at times it may be slippery and prone to wave wash. The intertidal zone is a large area with no paths and few distinguishing features; visitors could become disorientated in conditions of poor visibility. The intertidal zone in places is crossed by shallow channels at low tide, and it is subject to rapid tidal movements.
Safety of exposure(s)	The exposures flanking the harbour-wall walkway can be examined safely from the walkway. Outcrops in the intertidal zone are craggy and up to several metres high; in places, mild scrambling may be required to negotiate them. Seaweed, barnacles, limpets, etc., present potential slip-and-trip hazards.
Current condition	The exposures are generally clean and sound. Many of those closer to shore in the intertidal zone may have been worked for building stone in the past, and nearly all the best examples of pegmatite and miarolytic cavities have been damaged by mineral collectors.
Current conflicting activities	The intertidal zone is used for a range of recreational activities and enterprises, but its size means that problems are unlikely.
Restricting conditions	The best bedrock exposures are in the intertidal zone and will be inaccessible at times.
Nature of exposure(s)	In the intertidal zone, exposures take the form of scattered, craggy ‘islands’ of rock up to hundreds of metres long and *c.* 8 m high.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	This was the landing site of French troops in the Battle of Jersey in 1781. La Rocque has been a fishing 'village' at least since the Middle Ages. La Rocque Tower, a Conway

	tower built in 1779–80 (HER Number 0300081; Listed building GR0089). Resistance Nests La Rocque A and B are part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall (HER Number 0300050, 0300133; Listed building GR0080, GR0089). La Rocque Harbour was built from 1827–40 (HER Number 0300079; Listed building GR0079). La Platte Rocque consists of an important Victorian Gothic house and defensive military works dating from the 18th century (HER Number 0300080; Listed building GR0080). Bronze artefacts (HER Number 0300329). St Aidans is a late-18th- to early-19th-century house (HER Number 0300076; Listed building GR0076). Rock View is a 19th-century house (HER Number 0300074; Listed building GR0074). The 1-2 Harbour View sites are fisherman's cottages built in the mid- to late 19th century (HER Number 0300141; Listed building GR0141).
Aesthetic landscape	The parking area and harbour-wall walkway provide extensive and impressive views over the largest intertidal rock platform (or reef) on the Jersey coast.
History of Earth science	No known associations
Economic geology	Many of the exposures closest to the shore in the intertidal zone may have been worked for building stone in the past, although this may have been opportunistic rather than through organised enterprise. Large, euhedral crystals of quartz and feldspar, which were prized by collectors and might have had economic value, have been systematically removed from exposures of pegmatite in the most accessible parts of the site (and possibly more extensively).

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Local	Good	Descriptions	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site
The geoscientific value of the site comes from the range of features that can be viewed (geological, geomorphological and building heritage), the excellent exposures of *La Rocque granite* (which does not crop out in any other proposed geodiversity site), the unusual size and quality of pegmatite and miarolytic cavities and the number and quality of the exposures. The best miarolytic cavities in their original state would have been of exceptional quality, but unfortunately their value has been greatly reduced through damage caused by mineral collectors.

Assessment of Site: Current Site Usage	
Community	The modern beach is used for typical beach-related recreational activities, including 'rockpool rambles' run by the National Trust for Jersey and bioluminescence walks led by Jersey Walk Adventures.
Education	None known

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust, although many may have been modified in the past by the removal of stone for building purposes, and they are now subject to significant wave action. Pegmatite and miarolytic cavities are vulnerable to sample collecting, although most of the potential damage here has probably already been done (at least in the most accessible parts of the site).
Potential use	The site is aesthetically impressive and contains a range of geological, ecological and historical features; as such, it would be useful for school trips, higher education and special interest groups.

Site Photos:

Photo 1: Looking north from the walkway on the harbour breakwater past large exposures of La Rocque granite to Platte Rocque tower in the distance. BGS © UKRI 2020.

Photo 2: Looking south-east across the slipways at La Rocque and the exposed intertidal platform to distant Seymour Tower. BGS © UKRI 2020.

Photo 3: Looking south-west from the harbour breakwater across typical exposures of La Rocque granite in the intertidal zone at low tide. The nearest outcrop is around 5 m high and contains cross-cutting sheets of aplite. BGS © UKRI 2020.

Photo 4: Typical La Rocque granite exposed in the walkway beside the large outcrops shown in Photo 1. The rock consists of brick-red alkali feldspar, light orange plagioclase feldspar, grey quartz and specks of black biotite. Pen for scale. BGS © UKRI 2020.

Photo 5: A large patch of coarse pegmatite and an aplite sheet in La Rocque granite exposed on a large outcrop in the intertidal zone, *c.* 200 m south of the slipway at La Rocque. The pegmatite has been worked by mineral collectors, leaving numerous moulds that contained large euhedral crystals of quartz. See also Photo 8. BGS © UKRI 2020.

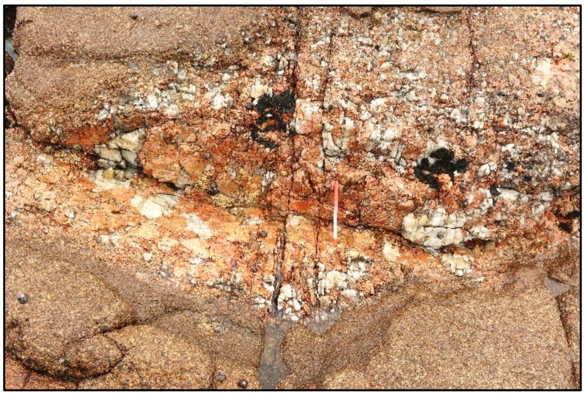


Photo 6: A large patch of coarse pegmatite in La Rocque granite exposed on a large outcrop in the intertidal zone, *c.* 200 m south of the slipway at La Rocque. BGS © UKRI 2020.

Photo 7: A small pegmatite patch in La Rocque granite exposed on a large outcrop in the intertidal zone, *c.* 200 m south of the slipway at La Rocque. Pen for scale. BGS © UKRI 2020.

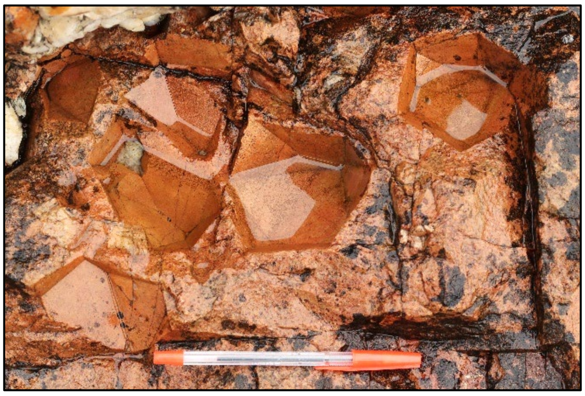


Photo 8: Angular moulds left in pegmatite after large euhedral crystals of quartz were removed by mineral collectors. From an outcrop in the intertidal zone, *c.* 200 m south of the slipway at La Rocque. Pen for scale. BGS © UKRI 2020.

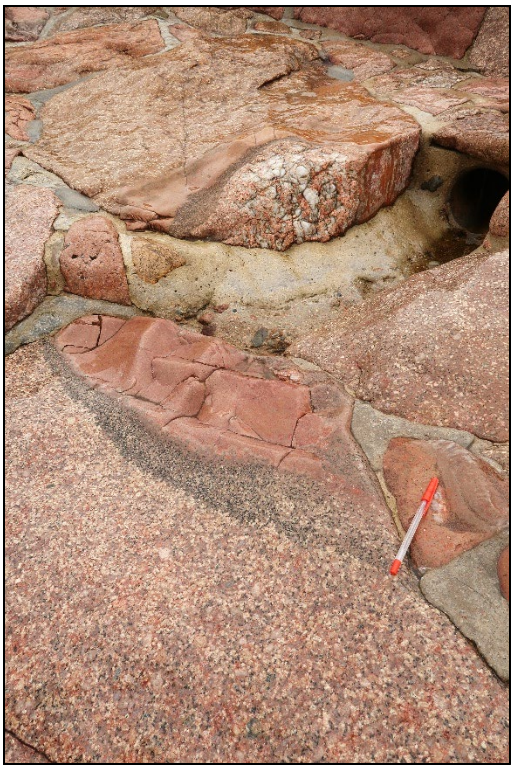
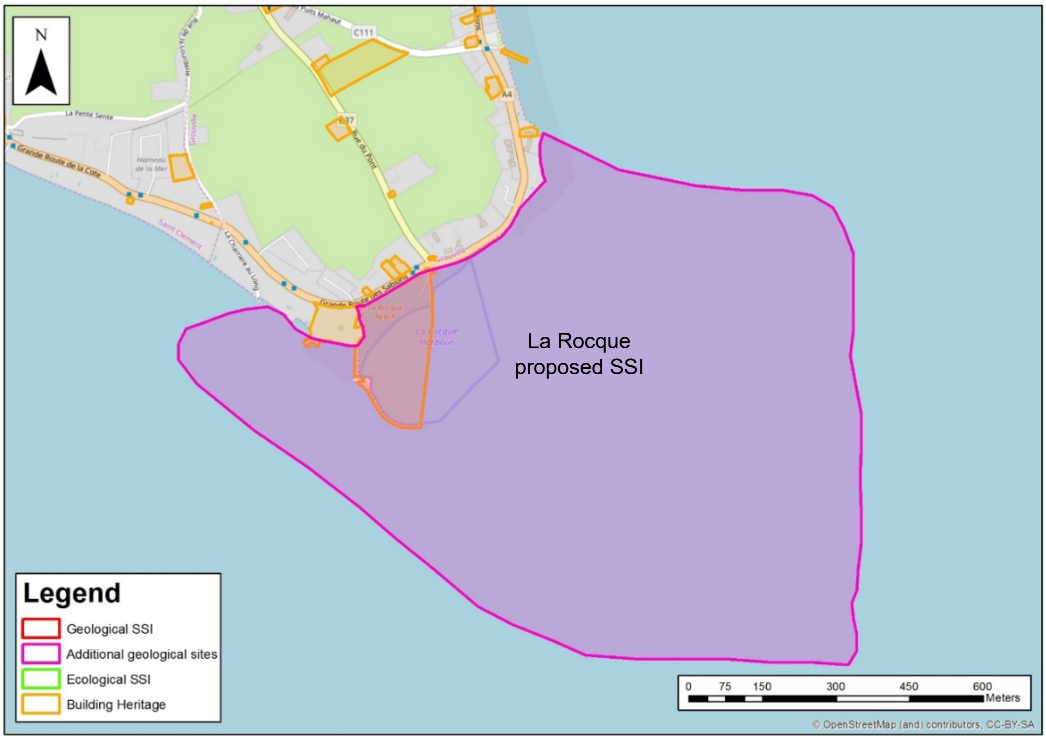


Photo 9: Large blocks of granite containing patches of coarse pegmatite, brick-red aplite and biotite-rich schlieren that were used to form the flanking walls of the slipways at La Rocque. The source of the blocks is not known. Pen for scale. BGS © UKRI 2020.

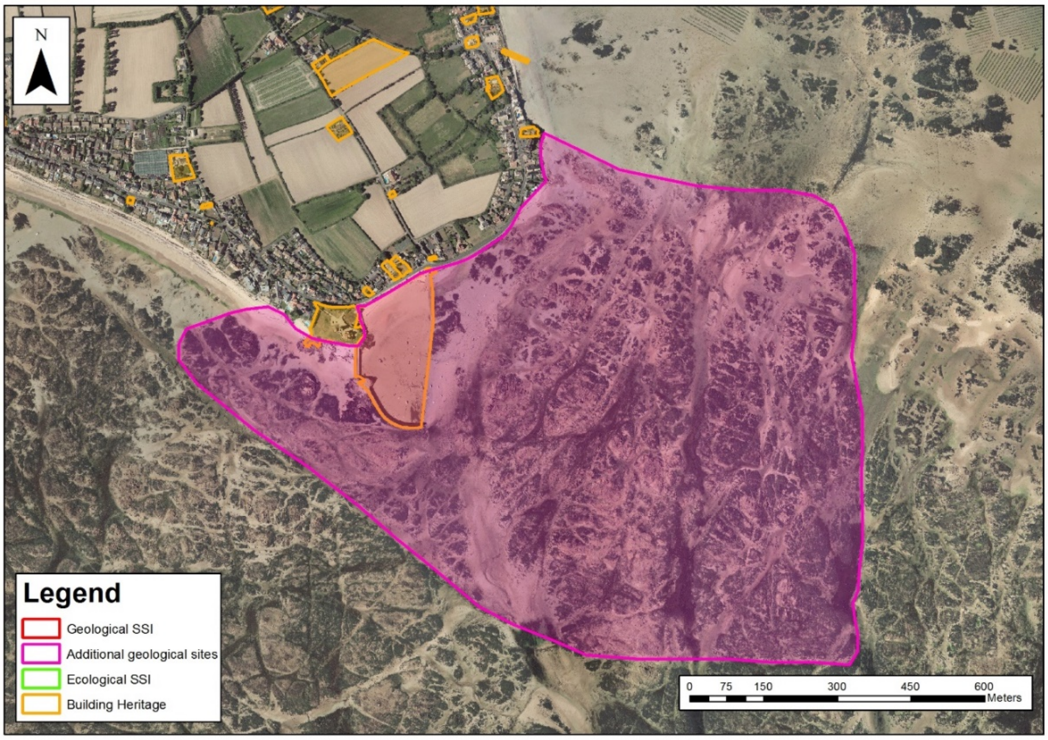
Photo 11: Setts of pale pink, coarse granite with occasional black enclaves, and dark pink, finer-grained granite used to form the slipway at La Rocque. Pen for scale. BGS © UKRI 2020.

 **Photo 10:** Uniform, pink granite, possibly Mont Mado granite, used to form the parking area wall at La Rocque. Pen for scale. BGS © UKRI 2020.	

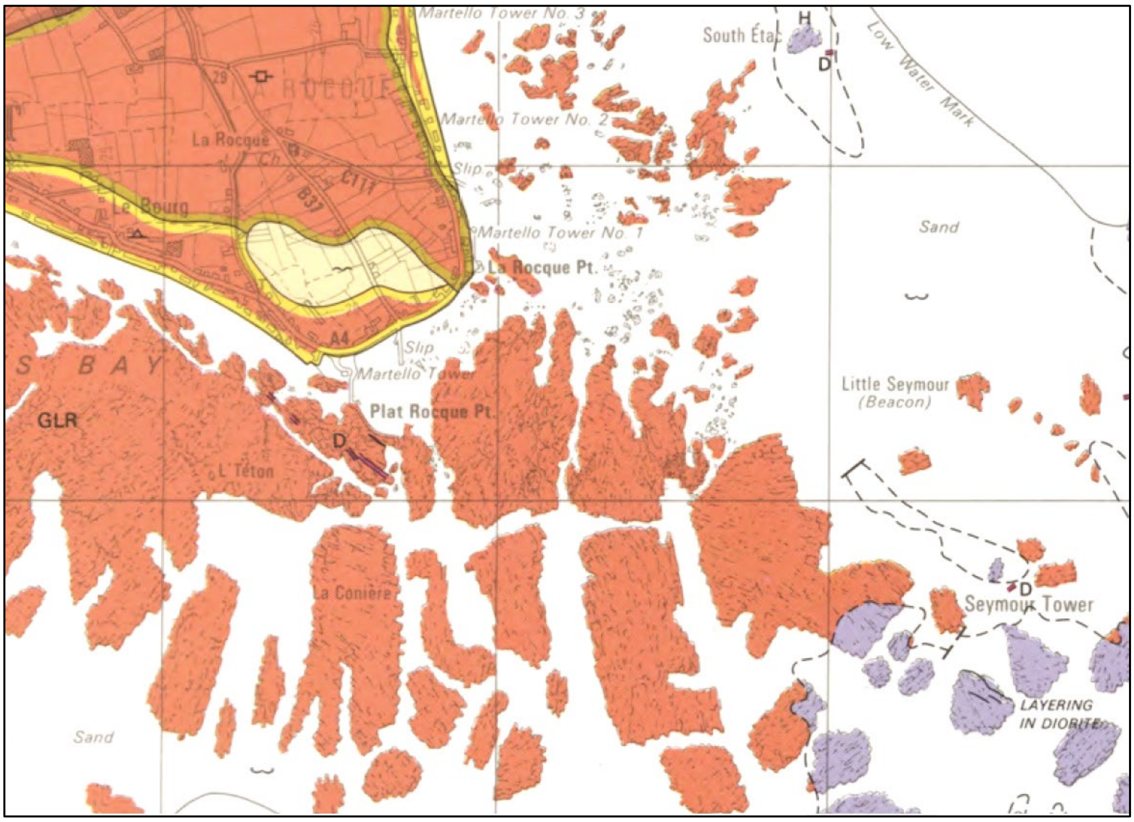
Map of the site boundary on a topographic base



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph
 Imagery ©2020 Government of Jersey.

Published geological map of the site

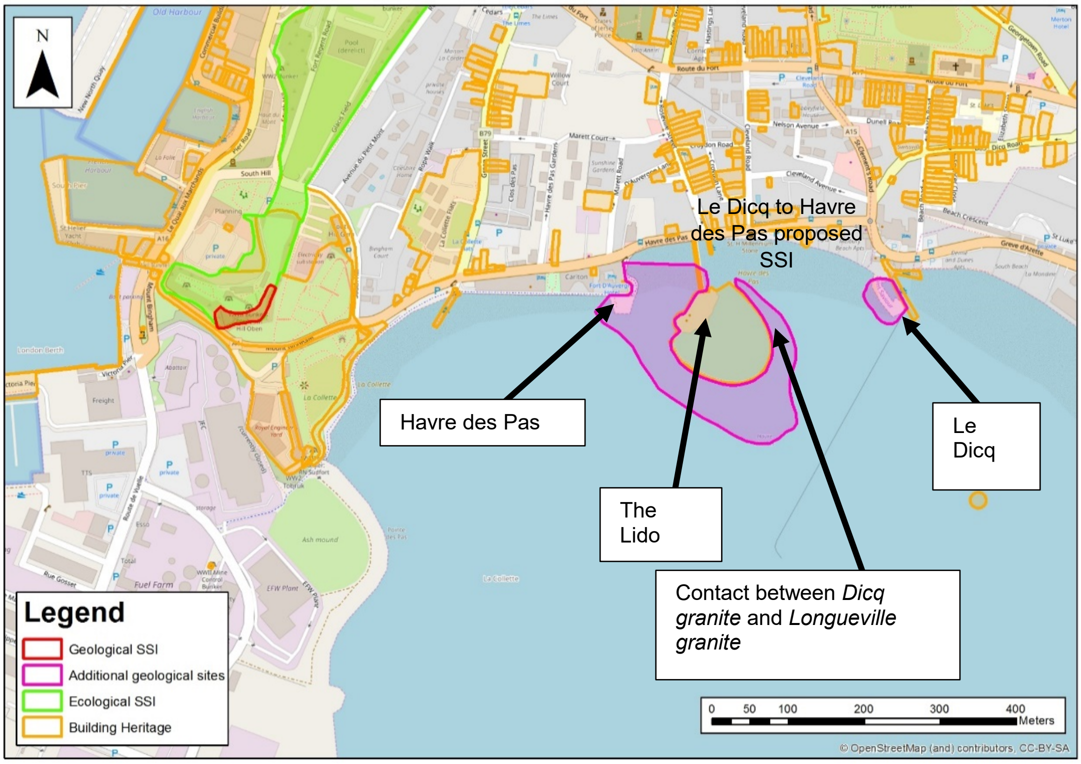


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

8.8 SITE NAME: THE DICQ TO HAVRE DES PAS, PROPOSED SSI

Site Information:	
The site, on the south coast of Jersey at St Helier, encompasses the intertidal zone between Le Dicq in the east and Havre des Pas Pier in the west. The bedrock is a lithologically variable part of the *South-east igneous complex*. The key geological features are contained in three separate outcrops within the intertidal zone. A large outcrop at the Dicq contains the best exposures of *Dicq granite* in any of the Jersey geodiversity sites. Low-lying exposures beside The Lido include a contact between *Dicq granite* and another granite body in the *South-east igneous complex*, possibly *Longueville granite*. Another large outcrop beneath Havre des Pas Pier presents spectacular examples of two types of magma interaction (magmatic brecciation and magma mingling) in multiple generations of diorite and granite; the resulting textures are clear evidence of a dynamic magma environment. Basalt dykes of the *Jersey Main Dyke Swarm* cut the outcrops at The Dicq and The Lido. Pleistocene sediments are also suspected to lie preserved under modern beach materials here, explaining the finds of well-preserved Middle Palaeolithic tools in this area.	
National Grid Reference: Mid-point: 42595, 64610 West end: 42371, 64595 East end: 42780, 64602	**Site Type:** Natural exposure
Site Ownership: To be confirmed	**Current Use:** Open country, coastal
Field Surveyors: M Gillespie and R Kendall	**Current Geological Designations:** None
Date Visited: 16 October 2019	**Other Known Designations:** The site encompasses a Building Heritage site (Havre des Pas Pool).

Site Map



Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** *South-east igneous complex* (Dicq granite)
Rock Types: Granite	
Age: Ediacaran Period (late Precambrian)	**Formation:** *South-east igneous complex* (Longueville granite)
Rock Types: Granite	
Age: Ediacaran Period (late Precambrian	**Formation:** *South-east igneous complex* (unnamed diorite mass)
Rock Types: Diorite and granite	
Age: Ediacaran Period (late Precambrian	**Formation:** Jersey Main Dyke Swarm
Rock Types: Basalt and dolerite	

Site Description:

Introduction

This relatively small site presents a remarkably wide range of intrusive igneous rocks and rock textures in several easily accessed outcrops that are of good quality. The rocks are all part of the *South-east igneous complex*, and collectively the outcrops provide insight into the processes that operate in dynamic magma chambers. One outcrop includes the best exposures of *Dicq granite* (a minor but visually distinctive component of the *South-east igneous complex*) in any of the Jersey geodiversity sites. A second outcrop includes the best exposure of *Longueville granite* (a major component of the *South-east igneous complex*) in any of the Jersey geodiversity sites and a well-exposed contact between *Dicq granite* and *Longueville granite*. The third outcrop presents a spectacular example of textures produced by different types of interaction between magmas of contrasting compositions. Basic dykes of the *Jersey Main Dyke Swarm* cut two of the outcrops.

Bedrock Units

South-east igneous complex

The *South-east igneous complex* is one of three major intrusion complexes in Jersey. Several lithologically distinct components have been mapped within it (Figure 1), including large (km-scale) masses of basic rock ('diorite and gabbro') and three main variants of granite (IGS, 1982).

The earliest facies of the *South-east igneous complex* comprises dark grey diorite, grading locally to gabbro. This facies forms several discrete, km-scale exposures. The largest of these underlies the intertidal reef off La Grève d'Azette and extends inland as far as Grouville; another substantial (km-scale) mass forms a cluster of reefs to the south of Seymour Tower, at the south-east extremity of the extensive reef lying south of La Rocque. Primary igneous layering in diorite and gabbro is preserved in several intertidal exposures, including exposures near La Grève d'Azette, at Le Nez and in the skerries south of Seymour Tower. The consistent character and orientation of the layering, which generally dips towards the north-east at around 60–70^0 (*c.* 30^0 near Seymour Tower), suggests that these widely separated outcrops were once part of the same large body of layered rocks, which was perhaps the earliest expression of the *South-east igneous complex*. Evidence for a dynamic magma environment, in the form of intimately associated and broadly contemporaneous but compositionally distinct basic, intermediate and siliceous rocks, is well displayed in several localities. Notable examples include the exposures between Le Croc and La Motte, at Havre des Pas Pier and at Elizabeth Castle (where the siliceous component is part of a km-scale mass sometimes referred to as the *Fort Regent Granophyre* [e.g., Bishop *et al.*, 2003]).

Injections of basic and siliceous magma may have destroyed early layering in parts of the magma chamber, and the early body of layered rocks may have been tilted and dismembered when large masses of granite magma (forming the three main granite variants of the *South-east igneous complex*) were subsequently emplaced.

The strongly porphyritic *Dicq granite* is the least extensive of the three mapped variants of granite in the *South-east igneous complex*; its outcrop is restricted mainly to a portion of the intertidal zone south of Grève d'Azette and near Havre des Pas, where the magma has cut and locally mingled with early dioritic rock. A further small (*c.* 100 x 100 m) outcrop of *Dicq granite* is mapped *c.* 1.2 km north-east of Le Dicq. The essentially non-porphyritic *Longueville granite* underlies a significantly larger area of ground beneath the south-east part of St Helier and to the north of the largest body of dioritic rock; however, exposure is very poor over most of the outcrop. *Longueville granite* and *Dicq granite* are probably broadly contemporaneous (see the description for the Le Dicq to Havre des Pas geodiversity site). *La Rocque granite* (called 'Le Hocq granite' by Lees [1986] and 'Le Hocq–La Rocque–Gorey granite' by Bishop *et al*. [2003]) is by far the most extensive granite component of the *South-east igneous complex*, at least onshore. It forms much of the intertidal reef in St Clement's Bay and crops out on the mainland north of there, as far as Mont Orgueil. Cross-cutting relationships with dykes in the *Jersey Main Dyke Swarm*, well displayed in intertidal exposures near La Grève d'Azette, indicate that *La Rocque granite* is also the youngest of the main granite components in the *South-east igneous complex* (IGS, 1982).

Unlike the other two large intrusion complexes in Jersey, the main components of the *South-east igneous complex* are not arranged in a pattern of concentric zones; instead, they form irregularly distributed and irregularly shaped, discrete, km-scale masses dominated by either diorite and gabbro or granite (IGS, 1982). The onshore outcrop of the *South-east igneous complex* (including the intertidal reefs) is at least 10 x 7 km in extent. However, granitic and dioritic rocks crop out on the seafloor for a considerable distance to the south, west and east of the south-east Jersey coast (BGS, 2000), suggesting that the onshore outcrop of the *South-east igneous complex* is just a small part of a much larger intrusive complex (Figure 6). Indeed, the offshore outcrop of intrusive igneous rocks extends unbroken along the entire south coast of Jersey, suggesting that the *South-west igneous complex* and *South-east igneous complex* are part of the same large outcrop of intrusive igneous rocks (Figure 6).

U-Pb zircon ages have not been reported for the *South-east igneous complex*. Instead, a range of ages between *c.* 583 and 527 Ma that are based on the K-Ar isotope system have been reported (Adams, 1967; D'Lemos *et al*., 1992). The K-Ar system is prone to resetting during rock alteration events, so it generally does not produce accurate dates for the crystallisation of coarse-grained igneous rocks; consequently, the results should not be compared directly with U-Pb zircon ages. Similarities in the character of cross-cutting dykes (*Jersey Main Dyke Swarm*), and the fact that intrusive plutonic rocks form an unbroken outcrop offshore between the south-west and south-east extremities of Jersey (Figure 6), suggest that the *South-west igneous complex* and *South-east igneous complex* are broadly contemporaneous. Based on this, the *South-east igneous complex* was probably emplaced during the Ediacaran Period, as a feature of the Cadomian Orogeny.

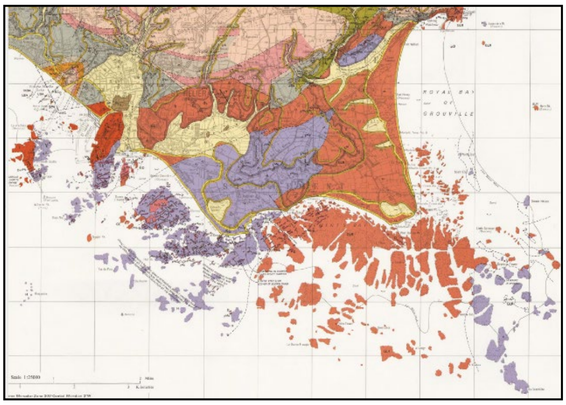


Figure 1. Geological map of the *South-east igneous complex*. From IGS (1982).

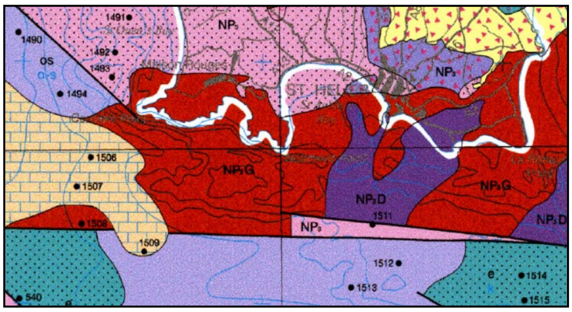


Figure 2. Map of onshore and offshore bedrock geology around the southern half of Jersey (coastline in white) showing the apparent offshore continuation of the *South-west igneous complex* and *South-east igneous complex*. From BGS (2000).

Jersey Main Dyke Swarm

The *Jersey Main Dyke Swarm* is the name assigned by Lees (1986) to the obvious concentration of dykes that crop out within the E–W-trending area of ground underlain by the two main igneous complexes in south Jersey. The dykes typically are steeply dipping, and most are less than 1 m wide; good coastal exposures reveal that they can account for around 10% of the outcrop locally. The swarm is particularly well exposed, and particularly abundant, in the extensive intertidal reef to the west and east of Le Croc in south-east Jersey.

The dykes display strong preferred orientations: E–W in the *South-west igneous complex*, and NE–SW in the *South-east igneous complex*. A small proportion of dykes have a broadly N–S trend; these dykes must have opened in a stress regime different from that of those forming the main part of the swarm, indicating that the swarm as a whole had a multistage emplacement history.

Dykes of basic (i.e., basalt and dolerite) composition predominate, but Lees (1986) noted that the dykes cutting the *South-west igneous complex* are mainly dolerite, whereas those cutting the *South-east igneous complex* display a broader range of compositions, including dolerite, microdiorite, lamprophyre and rhyolite (or microgranite). Where they occur together, for example, in exposures on the foreshore at Mont Orgueil, the basic (doleritic) dykes often cut the siliceous dykes. Many dykes are porphyritic; small phenocrysts of plagioclase and ferromagnesian minerals predominate in dykes of basic composition, while phenocrysts of quartz and feldspar occur in siliceous examples. Some dykes are composite, containing both basic and siliceous components; in such cases, basic margins and siliceous centres are common.

The dykes were emplaced during and shortly after the later stages of the assembly of the two main igneous complexes in south Jersey (Lees, 1986); thisplaces them in the Ediacaran Period (the youngest period of the Precambrian Era), as a late-stage feature of the Cadomian Orogeny. Based on whole-rock chemical analyses, Lees (1986) described the swarm as having a calc-alkaline character of a potassium-rich (‘high-K’) type ‘characteristic of basalts generated at an active continental margin’.

Dykes of similar lithologies, and often with similar trends, occur in other parts of Jersey, although they are relatively rare; many are probably genetically related to the *Jersey Main Dyke Swarm*.

Bedrock Features

Le Dicq

The large outcrop (roughly 60 x 35 x 10 m high at low tide) at Le Dicq consists almost entirely of *Dicq granite*. Natural weathering and erosion have produced generally smooth, rounded surfaces on the outcrop, but parts of its west side have flat surfaces and an angular geometry, indicating that the rock here has been quarried for building stone in the past (Photo 1).

Fresh granite is typically brownish grey, but most surfaces are weathered to reddish brown. Abundant, large phenocrysts of alkali feldspar make this rock among the most visually distinctive of the Jersey granites (Photo 2; see also Photo 5). The phenocrysts are tabular, euhedral and up to 25 mm long, and in this outcrop, many are concentrically zoned, with grey cores and brown rims. Plagioclase feldspar is typically white with a pale green or yellow tinge (best seen in Photo 5), and quartz is grey but can be difficult to see (the rock may have insufficient quartz to be true granite, and it may instead be quartz-monzonite). Ferromagnesian minerals, primarily biotite but possibly including a small proportion of hornblende, are fresh and black, comprising 8–10% of the rock.

Patches of dark grey, fine-grained rock (probably of diorite composition), usually a few centimetres across but extending up to several tens of centimetres in size, are scattered throughout the granite (Photo 2). These features, which are known as mafic enclaves, have smooth, rounded to lobate margins, and occasionally contain 'phenocrysts' of alkali feldspar that are identical to those in the adjacent granite and presumably were scavenged from it. These characteristics indicate that the enclaves consisted of magma (rather than solid rock) when they were incorporated into the granite magma. The enclaves probably formed when a batch of relatively basic magma was injected into the granite magma, whereupon the less viscous basic magma separated into globules and became dispersed in the more viscous granite magma.

A crude alignment of elongate feldspar crystals and slightly 'flattened' mafic enclaves can be discerned in places (Photo 2), notably on steep, flat, SSE-facing surfaces. This is an example of a pre-full crystallisation fabric; such fabrics form as magma flows or is compressed, which causes elongate crystals within the magma to become aligned. Geologists can use these fabrics to understand magma emplacement dynamics.

Planar to irregular sheets up to 30 cm thick of brick-red microgranite (sometimes referred to as felsite or aplite), with phenocrysts of feldspar and quartz, cut the granite locally; these may be a very late-stage product of the magmatism associated with *Dicq granite*, or they may be related to a younger component of the *South-east igneous complex*.

A set of four sub-parallel, sub-vertical dykes, the thickest of which is 1.2 m wide, cut through the granite at roughly the mid-point of the outcrop, trending NE–SW. The dykes, which are formed of dark grey dolerite and have very sharp, chilled margins against the granite, are likely to be part of the *Jersey Main Dyke Swarm*.

The Lido

The north-east end of the retaining wall for the outdoor swimming pool at The Lido sits on a long, low outcrop of igneous rocks; within this outcrop, there are several features of interest.

One part of the outcrop presents an excellent example of magmatic breccia, in which fragments of dark (relatively basic) rock are enclosed in typical Dicq granite (Photo 3). The fragments of basic rock have various grain sizes and partly angular surfaces and lack obvious chilled margins, indicating that they were probably derived from a pre-existing rock that was brecciated when the granite magma was emplaced. Some fragments have partly rounded surfaces, and in some cases, these may have developed through abrasion (i.e., mechanical erosion as the fragments were transported). However, some fragment surfaces are also 'indented' by crystals projecting from the granite, and some fragments contain 'phenocrysts' of alkali feldspar identical to those in the granite. This evidence suggests that some of the fragments were not fully solidified at the time that they were incorporated into the granite magma. Thus, the magmatic process that produced this rock may have included elements of brecciation (involving a rock and a magma) and mingling (involving two magmas).

The contact between *Dicq granite* and another granite intrusion is exposed in a low outcrop beside the north end of the retaining wall for the outdoor swimming pool (Photo 4). In contrast to *Dicq granite* (Photo 5), the most prominent constituent in this second granite consists of pale yellow, squat to stubby, euhedral crystals of plagioclase feldspar, which are up to 1 cm long (Photo 6). Orange alkali feldspar, grey quartz and black ferromagnesian minerals (probably mainly biotite, but possibly including hornblende) occupy the spaces between the plagioclase crystals. Other than very near to the contact, the crystals have no preferred orientation. As with *Dicq granite*, the rock may have insufficient quartz to be true granite, and instead may be quartz-monzonite. This second granite is probably *Longueville granite* (another major component of the *South-east igneous complex*), the main outcrop of which is shown to underlie onshore areas immediately north and west of Le Dicq on the geological map of Jersey (IGS, 1982).

The contact between the two granites is razor-sharp, and in places on the '*Longueville granite*' side, it is accompanied by several dark bands rich in ferromagnesian minerals, which are developed within 20 cm or so of the contact and parallel to it (Photo 4). In one or two places, small 'dykes' of *Dicq granite* appear to cut the *Longueville granite*, but there is no discernible chilling on either side of the contact and the two appear to be essentially co-magmatic (i.e., both were in a molten state at the time they came into contact). The fact that they probably had similar temperatures, bulk compositions and viscosities may explain why there appears to have been essentially no mingling or mixing of the two magmas. The contact, which can be traced along at least 6–7 m of the outcrop, is somewhat contorted in detail but trends essentially E–W overall.

The outcrop is cut by a basalt dyke less than 1 m wide. The dyke has the same trend, and lies directly along the strike of, the set of dykes described in the outcrop at Le Dicq; like them, it is likely to be a component of the *Jersey Main Dyke Swarm*.

Extensive low outcrops beneath the west side of The Lido are formed of dark reddish-brown aplogranite (which could also be called felsite), with phenocrysts of feldspar and quartz. The outcrops are angular and have clearly been worked for building stone, perhaps to prepare foundations for The Lido and the pier leading to it. On the geological map of Jersey (IGS, 1982), 100-m-scale bodies of aplogranite are shown to crop out around and south of The Lido and on large intertidal outcrops that are 1 km or so to the south-east at Grève d'Azette.

Havre des Pas Pier

The east end of Havre des Pas Pier sits on a large outcrop of igneous rock (roughly 60 x 40 x 6 m high at low tide) that presents spectacular examples of two types of magma interaction (magmatic brecciation and magma mingling) in multiple generations of diorite and granite (Photos 7–10). These rocks form the eastern limit of one of the unnamed early diorite-dominated masses in the *South-east igneous complex*, and they almost certainly pre-date all the rocks exposed in the outcrops at The Lido and Le Dicq.

Most of the outcrop consists of fragments of dark rock (probably of diorite composition) enclosed in (and in places cut by) pale granitic rock (Photos 7–9). The fragments generally have sharp, angular boundaries, indicating that the diorite crystallised first and was solid enough to break into fragments when granite magma was emplaced forcefully into the same part of the magma chamber. This rock can therefore be described as magmatic breccia. However, in some parts of the outcrop, the diorite and granite components are separated by lobate and diffuse boundaries (Photo 10), which indicate that both components were in a non-solid (essentially magmatic) state when they came into contact, thereby producing a weakly mingled (rather than brecciated) texture.

Careful inspection reveals subtle variations in the colour and grain size of the granite component, suggesting that the granite was emplaced in at least two phases: for example, later, slightly paler and coarser-grained granite enclosing rounded masses of slightly darker and finer-grained granite can be discerned in the exposure shown in Photo 9. The rounded and in places diffuse and irregular contacts between these two granite phases suggest that they too were essentially contemporaneous magmas that mingled on the outcrop scale.

The outcrops below Havre des Pas Pier thus preserve a record of dynamic magmatism and the intimate interactions of at least two compositionally distinct magmas and their solidified products.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	The site has excellent road access but no designated parking. Parking is possible on the slipway at Le Dicq, and on-street parking may be possible on streets close to The Lido and Havre des Pas Pier.
Access	All of the key exposures are in the intertidal zone. A slipway provides easy access to a narrow breakwater beside the outcrop at Le Dicq; a vertical drop of around 1 m off the breakwater must be negotiated to reach the beach from which the outcrop at Le Dicq can be examined. From the outcrop at Le Dicq, a sand beach must be crossed to reach the outcrops near The Lido and Havre des Pas Pier. Steps from the promenade beside Havre des Pas provide direct access to the beach near The Lido; from there, all the outcrops can be reached. The outcrop on the east side of the Lido can be examined from the beach or from the top of the retaining wall for the outdoor swimming pool.
Safety of access	Access to the beach via either the slipway at Le Dicq or steps from the promenade at Havre des Pas is generally straightforward. However, a vertical drop of around 1 m off a breakwater must be negotiated to reach the beach from the slipway at Le Dicq, and both the slipway and steps may be slippery at times.
Safety of exposure(s)	The exposures are formed of rough, rocky ground that is exposed to wind and waves. The rock may be slippery, and mild scrambling is required to access some parts.
Current condition	The exposures are generally clean and sound. All of the outcrops may have been worked for building stone in the past. Barnacles, limpets and algae coat the rock to varying degrees, but there is little seaweed.
Current conflicting activities	A public building – The Lido – is built on part of the outcrop.
Restricting conditions	The bedrock exposures are mainly in the intertidal zone and will be inaccessible at times.
Nature of exposure(s)	Rocky outcrops up to 60 m long and 10 m high separated by large expanses of sand and pebble beach

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Havre des Pas Bathing Pool, built in 1865, is an early example of an outdoor seaside swimming pool (HER Number 0400266; Listed building HE0266). Fort D'Auvergne is the surviving part of La Garde du Havre des Pas, which was built *c.* 1756 (HER Number 0401102; Listed building HE1102). Le Rocher des Proscrits is a rocky outcrop that has a plaque, added in 1954, in memory of Victor Hugo, who lived in the Havre des Pas area (HER Number 1100260). The Allix shipbuilding yard operated starting in 1830, and a gap was left when the sea wall was built through which the ships could be launched. This can still be seen, although it is now blocked in. The first boat built here was the Jupiter in 1832, and the last boat constructed here was built in 1904.
Aesthetic landscape	The site includes a pleasant beach but is low-lying and adjacent to an urban area.
History of Earth science	None known
Economic geology	None

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Local	Good	References	X
Structural geology				
Palaeontology				
Geomorphology				

Geoscientific Value of the Site

The site presents examples of most of the main named and unnamed components of the *South-east igneous complex* in several easily accessed outcrops of good quality. These components include one of the unnamed early diorite-dominated masses, both the *Longueville granite* and *Dicq granite* and one of the unnamed masses of aplogranite. Collectively, the outcrops also contain a remarkably wide range of the rock textures and inter-component relationships that can form in dynamic magma chambers, which in general are clearly displayed, making them easy to appreciate.

Assessment of Site: Current Site Usage	
Community	The modern beach is used for typical beach-related recreational activities.
Education	None known

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust.
Potential use	The site is easy to access and contains a range of geological, ecological and historical features; as such, it would be useful for school trips, higher education and special interest groups, and it may be suited to being part of a geotrail.

Site Photos:

Photo 1: Looking north-east towards the large outcrop at Le Dicq, which is formed almost entirely of Dicq granite. The smooth surfaces and angular intersections of many faces indicate that stone has been quarried from the outcrop in the past. The outcrop is around 10 m high. BGS © UKRI 2020.

Photo 2: Dicq granite exposed in the large outcrop at Le Dicq. Large, tabular phenocrysts of orange alkali feldspar are clearly visible, and a faint pre-full crystallisation (PFC) fabric is preserved in a crude top-left to bottom-right alignment of their long axes. There are several dark grey mafic enclaves near the pen. Pen for scale. BGS © UKRI 2020.

Photo 3: Magmatic breccia comprising fragments of dark, relatively basic rock enclosed in lighter Dicq granite. The exposure is below the retaining wall of the outdoor swimming pool at The Lido. Pen for scale. BGS © UKRI 2020.

Photo 4: Part of the contact between orange Dicq granite and yellowish Longueville granite, exposed below the retaining wall of the outdoor swimming pool at The Lido. Dark bands rich in ferromagnesian minerals are developed in the yellowish granite near the contact. Pen for scale. BGS © UKRI 2020.

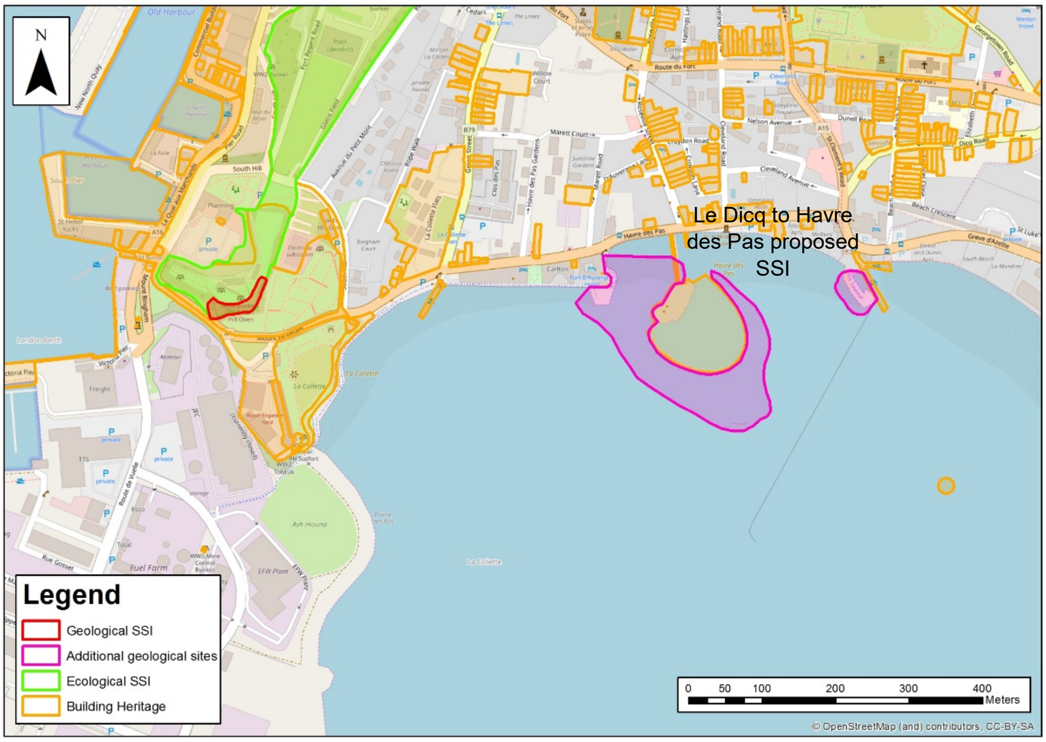
Photo 5: Typical Dicq granite exposed below the retaining wall of the outdoor swimming pool at The Lido. The rock has phenocrysts of orange alkali feldspar with yellow plagioclase feldspar, grey quartz (hard to see) and black ferromagnesian minerals developed interstitially. This view includes a dark mafic enclave. Pen for scale. BGS © UKRI 2020.

Photo 6: Typical Longueville granite exposed below the retaining wall of the outdoor swimming pool at The Lido. The rock has abundant crystals of yellow plagioclase feldspar, with orange alkali feldspar, grey quartz (hard to see) and black ferromagnesian minerals developed interstitially. Pen for scale. BGS © UKRI 2020.

Photo 7: Exposures beneath Havre des Pas Pier showing intimately associated grey dioritic rocks and pink granitic rocks. The textures indicate that the granite magma was emplaced into partly solidified dioritic rock (see the following photographs). Figure for scale. BGS © UKRI 2020.

Photos 8, 9 and 10 (top to bottom): Exposures beneath Havre des Pas Pier, showing intimately associated grey dioritic rocks and pink granitic rocks. In most of the outcrop, angular fragments of dioritic rock enclosed in granitic rock, and veins of granitic rock in the dioritic rock, indicate that the granite magma was emplaced into solidified dioritic rock (Photos 8 and 9). However, lobate and diffuse boundaries between the two components in some parts of the outcrop (Photo 10) indicate that both must have been in a semi-solid or wholly magmatic state when they interacted. At least two generations of granitic rock, revealed by subtle differences in grain size and colour, are discernible in places (e.g., two granite components are faintly visible in the left half of Photo 9). Pen for scale. BGS © UKRI 2020.

Map of the site boundary on a topographic base

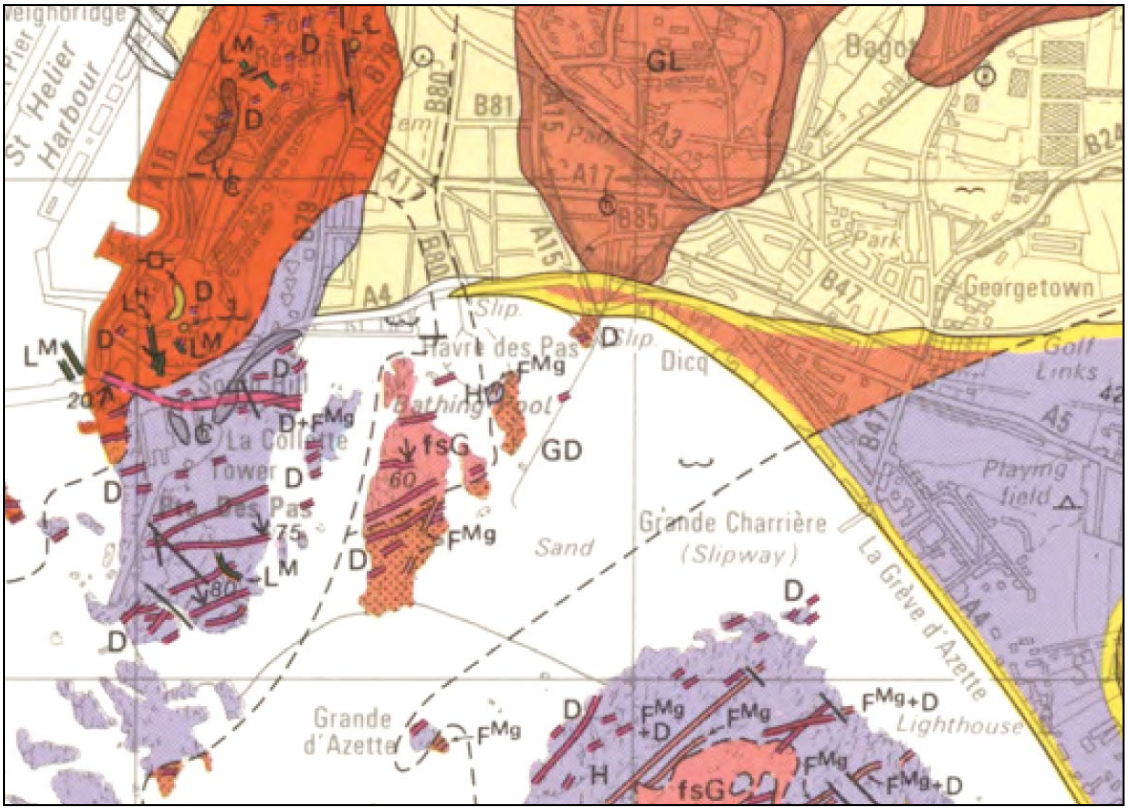


Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph

Imagery ©2020 Government of Jersey.

Published geological map of the site

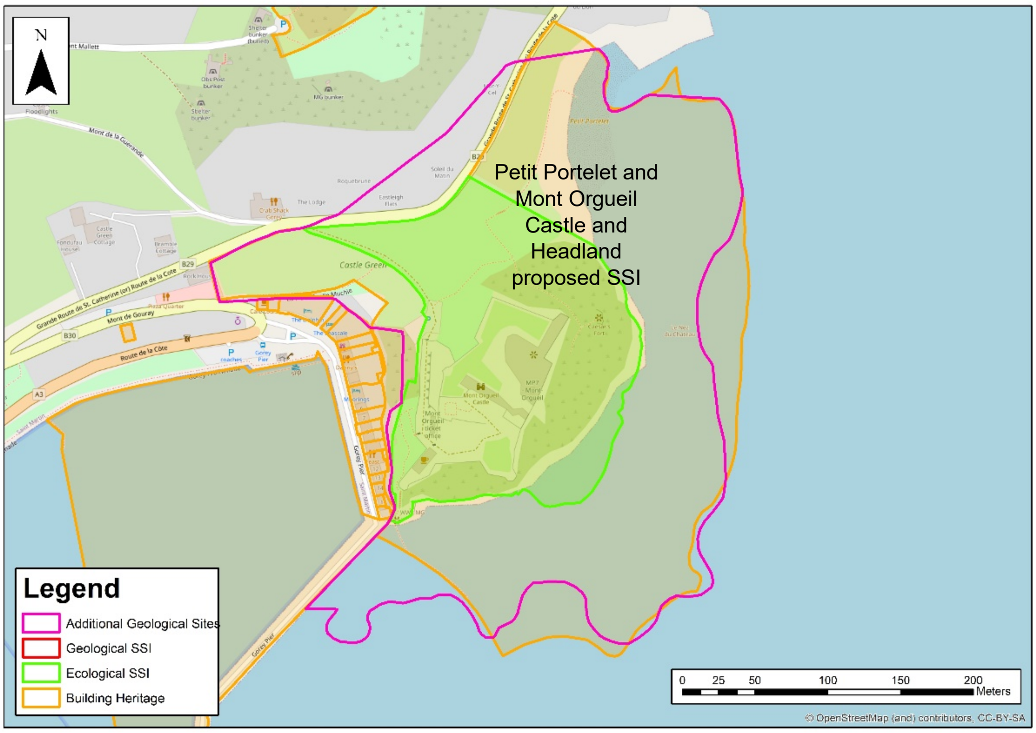


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

8.9 SITE NAME: PETIT PORTELET AND MONT ORGUEIL CASTLE AND HEADLAND, PROPOSED SSI

Site Information:	
Mont Orgueil Castle stands proudly on a significant granite headland at the northern end of the Royal Bay of Grouville on Jersey's east coast. The headland exists due to the resistance of the underlying granite to high-energy coastal erosion and weathering, and it has provided a place of defence and refuge since the Neolithic period. The granite belongs to the *South-east igneous complex* and is well exposed in the surrounding intertidal areas, as are a number of minor intrusions into the granite, including porphyritic microgranite, banded rhyolite, diorite and mica-lamprophyre dykes. Sections through raised beach deposits and head, which mantle the granite, can also be viewed on the eastern and northern side of the headland.	
National Grid Reference: Mid-point: 48516, 67156 North end: 48605, 67371 South end: 48351, 66997	**Site Type:** Natural section/exposure
Site Ownership: To be confirmed	**Current Use:** Open country, coastal
Field Surveyors: S Arkley, C Auton and M Pope	**Current Geological Designations:** None
Date Visited: 16 October 2019	**Other Designations:** Ecological SSI: Mont Orgueil. Building Heritage: Mont Orgueil Castle (MN0181) overlaps with much of the site. Gorey Harbour (MN0297) and numerous small sites lie adjacent to the site. Other: Areas above the HWM are within Jersey National Park.

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Ediacaran Period (late Precambrian)	**Formation:** *South-east igneous complex*
Rock Types: Coarse-grained granite of La Rocque type	
Age: Ediacaran Period (late Precambrian)	**Formation:** Dykes and sills
Rock Types: Mica-lamprophyre dykes, porphyritic microgranite dykes, dolerite dykes and flow-banded rhyolite dykes	
Age: Quaternary	**Formation:** Loess
Rock Types: Silt and find sand	
Age: Quaternary	**Formation:** Head
Rock Types: Angular blocks of scree up to 1 m in diameter	
Age: Quaternary	**Formation:** Raised beach
Rock Types: Rounded cobbles	

Site Description:

Introduction

Mount Orgueil Castle stands on a granite headland of the *South-east igneous complex*. The site mainly covers the bedrock exposures in the intertidal area around the Mont Orgueil headland, Quaternary sections in the cliffs surrounding the headland and in the bay of Petit Portelet (north of the castle) and bedrock exposures within the castle walls of La Rocque granite of the *South-east igneous complex*. Numerous NW-SE-trending dykes cut the granite in the foreshore exposures. Particularly good examples of rhyolite dykes, which display flow banding parallel to their margins, are present on the foreshore; some of them are cut by later fine-grained basic dolerite dykes with chilled margins. Good examples of mica-lamprophyre dykes are also seen on the foreshore exposures north of the castle. A number of ENE-trending dykes and sheets, mainly composed of porphyritic microgranite, are also present. The dykes are up to 10 m across; some have cross-cutting relationships and others display composite structures with doleritic margins.

The cliff exposes a deep sequence of Pleistocene head deposits, which infills the void between the granite stack of Mont Orgueil and the fossilised cliff line that extends to the west. Within this sequence of head deposits, rounded beach gravels that have been dated to the last interglacial are present. Palaeolithic artefacts have been collected from the cliffs and beach since the beginning of the 20^{th} century. Recent excavations in the intertidal zone have revealed that fine-grained deposits preserved within gullies in the rock geology at the base of the sequence preserve fresh Middle Palaeolithic artefacts in at least two separate localities. The OSL dating of the associated sediments suggests that these artefacts date to the mid-Weichselian period.

Bouldery head deposits up to more than 10 m thick mantle the granite on the eastern side of the headland and also overlie a small exposure of raised beach gravel.

Bedrock Units

South-east igneous complex

The granite that forms the Mont Orgueil headland is La Rocque granite of the *South-east igneous complex*; it typically comprises pink-weathering granite of potassic feldspar, with plagioclase, quartz, biotite and hornblende and with zircon, apatite and allanite as accessory minerals. However, at Mount Orgueil, the granite is brownish, and quartz is less abundant than normal for La Rocque granite. The granite at this locality also includes inclusions of rhyolite (Bishop and Bisson, 1989).

La Rocque-type granite occupies a large area extending from Grouville Arsenal to Gorey, La Rocque and the tidal reefs in St Clement's Bay (Bishop and Bisson, 1989). It is assumed to be faulted against volcanic rocks in Petit Portelet Bay and is seen to intrude the *Jersey Shale Formation* near the slipway west of Gorey Harbour, beyond the margin of this site (Photo 1). Examples of irregular pods of dark orange-brown microgranite (Photo 3), stringers of fine-grained basic igneous rock (Photo 4) and pegmatitic patches (Photo 5) can also be seen at this locality.

There are at least four types of minor intrusions exposed at the site:

1. Microgranitic dykes, sheets and pods
Intrusions of this type are fairly widespread in Jersey, but most are confined within the dyke swarm on the south-eastern part of the Island (Bishop and Bisson, 1989). They are recorded as generally being 4 to 10 m wide. Some are simple intrusions (Photo 3), but many are composite types with relatively thin basic margins. Several examples occur within the exposures south of the Mont Orgueil headland. Individual dykes, which have been classed as microgranitic by Bishop and Bisson (1989), show a range of textures that vary between flow-banded rhyolite and microgranite (Photo 6). The details of the flow banding are shown in Photos 7 and 8. The rhyolite/microgranite dyke is cut by a later, thinner, fine-grained basic dyke, which also cuts through the main body of the coarse-grained granite (Photo 9). Both dykes are near-vertical intrusions with sharp planar contacts with the granite host rock, and their cross-cutting relationships clearly illustrate their relative ages.

2. Flow-banded rhyolite
A good example of a flow-banded rhyolite dyke cuts the granite exposed near the Gorey Harbour wall (Photos 10 and 11). This intrusion is at least 3 m thick and has a dark grey, fine-grained basic margin at its contact with the granite host rock.

3. Basic doleritic dykes with chilled margins
Numerous fine-grained basic dykes cut through the exposures of granite in the foreshore reefs. Most of the dykes are less than 50 cm thick and are mapped as dolerites of the Jersey Main Dyke Swarm (Photos 12 and 13). The dykes form vertical or steeply inclined structures, with planar or sharp irregular chilled margins. They consist of dark grey, micro-crystalline rocks containing fresh or relict pyroxene, often with primary or secondary amphibole. At this site, they are demonstrably younger than acid minor intrusions.

4. *Mica lamprophyre*
At the Mont Orgueil site, planar-sided, near-vertical intrusions of mica-lamprophyre sheets can be seen cutting La Rocque granite; they are typically about 1 m thick (Photos 14–18). The dykes contain abundant altered biotite mica, giving the rock a characteristic ‘glittery’ appearance. They typically also display the prominent zonation of coarser- and finer-grained rock parallel to the dyke margins, giving the exposures a typical ‘ribbed’ aspect.

5. *Biotite lamprophyre*
The biotite lamprophyres occur as medium to dark brown, coarsely crystalline dykes, with large, brown, highly reflective biotites and altered biotites in a friable groundmass. They are therefore softer than the rocks into which they are intruded, and they weather and erode to produce gullies, such as the gully seen in the granite on the south side of Mont Orgueil (Photo 18). This dyke has a thickness comparable to that of the exposed mica-lamprophyre dyke cutting the Fort Regent Granodiorite at the South Hill site, although the latter is slightly lighter in colour.

Other dark grey, fine-grained basic rocks are present as deformed lenses, discrete broken-up thin stringers and veins within the main body of the granite intrusion (see Photo 4).

Age

Unlike the other two main intrusion complexes in Jersey, a U-Pb zircon age has not been reported for the *South-east igneous complex*. Instead, a range of ages between *c.* 583 and 527 Ma that are based on K-Ar isotopic dating have been reported (Adams, 1967; D’Lemos *et al*., 1992). The K-Ar system is prone to resetting during rock alteration events, so it generally does not produce accurate dates for the crystallisation of coarse-grained igneous rocks; consequently, the results should not be compared directly with U-Pb zircon ages. Similarities in the characteristics of cross-cutting dykes (*Jersey Main Dyke Swarm*), and the fact that intrusive plutonic rocks form an unbroken outcrop offshore between the south-west and south-east extremities of Jersey (Figure 6), suggest that the *South-west igneous complex* and *South-east igneous complex* are broadly contemporaneous. Based on this, the *South-east igneous complex* was probably emplaced during the Ediacaran Period (Late Precambrian), as a late-stage feature of the Cadomian Orogeny.

The dykes of the Jersey Main Dyke Swarm were emplaced during and shortly after the later stages of the assembly of the two main igneous complexes in south Jersey (Lees, 1986); this places them in the Ediacaran (late Precambrian), as a late-stage feature of the Cadomian Orogeny.

The lamprophyre dykes have not been dated but have been observed cutting all the main bedrock units in Jersey, including the Ordovician *North-west igneous complex* and the *Rozel Conglomerate Formation*. They appear therefore to be the youngest bedrock features in Jersey, and they may be related to the Variscan (also known as the Hercynian) Orogeny.

Quaternary Sediments

The granite outcrops on which the castle at Mont Orgueil is built form steep cliffs that are mantled in places by bouldery head deposits of variable thickness. These deposits are best exposed in a section below the north-eastern side of the castle walls (Photo 19). The head deposits infill a gulley in the bedrock. The lower part of the head contains abundant angular blocks of scree up to >1 m in diameter, derived from the adjacent fractured granite. A unit of cobbly head occurs in the middle of the section, and finer-grained head with a silty loessic matrix is visible near the top of the section. The steepness of the cliff makes it too difficult and dangerous to examine these deposits closely.

A second Quaternary section occurs just to the north in vegetated cliffs at the back of Petit Portelet Bay (Photo 20). This section displays deposits of the 8 m raised beach at the base of the cliff (to the right of the rucksack); they are overlain by up to 4 m of gently dipping loessic head deposits. The loessic head is overlain by further boulder-scale head deposits, which may have other intercalations of silty head within them. Again, the steepness of the cliff and its vegetation cover make more detailed descriptions of the stratigraphy difficult. The raised beach deposits at the base of the Quaternary section are, however, easily accessible. The raised beach deposit, which is overlain by silty loessic head, consists of well-rounded, clast-supported cobbles and pebbles of coarse- and fine-grained igneous rocks in a matrix of loessic silt (Photo 21). The silt was probably translocated downwards, to infill voids, in the formerly open-work beach gravel. The beach deposit is underlain by older head deposits, which are preserved under the modern beach and in the intertidal zone within gullies in the bedrock. These deposits comprise silts and clays of apparently primary and secondary loess deposition. The head deposits contain fresh, apparently primary content Middle Palaeolithic artefacts, which reflect the activity of Neanderthal people at this locale during the Middle or Late Pleistocene. These sites, including their ages, were under study at the time of writing. No organic material, such as bone, antler or plant remains, has been recovered from these head deposits so far.

Although head is mapped mantling the granite headland and backing the beach at Petit Portelet, there appears to have been little detailed study of the deposits at either locality. Both Bishop and Bisson (1989) and Bishop *et al.* (2003) mentioned that good exposures of head occur in the cliffs of Petit Portelet Bay; the latter state that 'good exposures of head up to 10 m thick' are present at Petit Portelet. There appears to be no previous record of the 8 m raised beach at the Petit Portelet Bay exposure described here, and it is not included in Keen's inventory of raised beach localities (Keen, 1978b). The nearest mapped occurrence is a small exposure at Anne Port, to the north. This may suggest that the exposure of raised beach gravel at Petit Portelet is a new occurrence and that the gravel

was formerly concealed beneath the silty head deposit at the base of the cliff and has now been revealed by recent erosion. The variation in the sediments and the lack of stratigraphic continuity of the head deposits at this site between the two exposures, which are only a few hundred metres apart, clearly illustrate the complexity of these periglacial sequences and the difficulties in correlating them.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Parking is possible within the village of Gorey and along Gorey Promenade. A number of bus routes also stop at Gorey. The southern end of the site can be viewed from the harbour wall and from within the castle.
Access to the site	There is open access onto the foreshore from both ends of the site. A set of granite steps leads down from the harbour wall at the southern end of the site, and a small footpath descends down to the bay of Petit Portelet at the northern end of the site.
Safety of access	There is fairly easy access to the foreshore, although the stone steps down from the harbour wall may be slippery when wet. All visitors should be aware of the tide times and access routes when planning a visit, as many of the bedrock exposures are only visible at low tide. It is easy to be cut off by the tide at this locality.
Safety of exposure(s)	The cliff sections exposing the raised beach / head deposits at the back of Petit Portelet and east of the castle appear to be generally stable, but care should always be taken beneath cliffs, particularly in any overhanging areas. The bedrock exposures are largely in the intertidal area and have uneven, water-worn surfaces, which are often slippery with algae and seaweed.
Current condition	Many of the rock exposures are clean and free of vegetation. However, in the intertidal zone, the rocks are covered by barnacles, algae and seaweed in places.
Current conflicting activities	None known
Restricting conditions	Bedrock exposures are dominantly in the intertidal zone and therefore covered at high tide. The Quaternary sections in Petit Portelet Bay have no known restrictions, as they lie above the normal high-tide mark.
Nature of exposure(s)	Intertidal and backshore bedrock exposures, and Quaternary cliff sections

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Mont Orgueil Castle is located on the rocky headland immediately north of the harbour at Gorey, overlooking the Royal Bay of Grouville. The site has natural protection on three sides (cliffs and sea) and has been used as a place of defence and refuge since the Neolithic period (around 3,000 BC). It is one of the finest examples of a medieval fortress in existence and has witnessed many of the key events that have shaped Jersey's history. Le Petit Portelet has Pleistocene deposits that represent an early Middle Palaeolithic site (HER Number 0700337; Listed building MN0181). Bowl/jug (HER Number 0700227). Mont Orgueil Castle was built from 1204–1470 (HER Number 0700181; Listed building MN0181). The

	following properties are important due to their link to the Victorian development of Gorey Harbour: Cafe Louise (HER Number 0700021), Neptune (HER Number 0700020; Listed building MN0020), Dolphin Hotel (HER Number 0700019; Listed building MN0019), 17 Gorey Pier/Seascale Hotel (HER Number 0700017; Listed building MN0017), Fountain Court (HER Number 0700016; Listed building MN0016), The Beach House (HER Number 0700295; Listed building MN0295), 1–2 Gorey Pier (HER Number 0700014; Listed building MN0014), 3–5 Gorey Pier / The Moorings Hotel (HER Number 0700013; Listed building MN0013), 6 Gorey Pier (HER Number 0700001; Listed building MN0001), 7 Gorey Pier (HER Number 0700002; Listed building MN0002), 8 Gorey Pier (HER Number 0700003; Listed building MN0003), 9 Gorey Pier (HER Number 0700004; Listed building MN0004), 10–11 Gorey Pier (HER Number 0700012; Listed building MN0012), 12 Gorey Pier (HER Number 0700005; Listed building MN0005), 13 Gorey Pier (HER Number 0700010; Listed building MN0010). 15 Gorey Pier, formerly the Harbour Master's house, was built in the mid-19th century (HER Number 0700007; Listed building MN0007). Gorey Harbour was built in the 19th century, with earlier origins. The beach at Gorey has been used for loading cargo since at least the Middle Ages (HER Number 0700297; Listed building MN0297). Victoria Tower is a Martello tower built in 1837 (HER Number 0700063; Listed building MN0063). Strongpoint Victoria Tower is part of an integrated network of German defensive structures constructed in Jersey during the Second World War that were more widely part of the Atlantic Wall (HER Number 0700256; Listed building MN0256).
Aesthetic landscape	Coastal – Located on the eastern coast of Jersey, the headland has amazing views across the sea to the French coast on a clear day.
History of Earth science	No known association
Economic geology	No known association

Assessment of Site: Geoscientific Merit

	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy	Local	Good		
Sedimentology				
Igneous/mineral/meta	Local	Good	Referenced	X
Structural geology				
Palaeontology				
Geomorphology				
Prehistory	Regional	Excellent		X

Geoscientific Value of the Site

Easily accessible and extensive exposures of the *South-east igneous complex* can be viewed at this site, with the added geological interest of multiple and varied minor intrusions cutting through the granite. The site is a particularly good place to establish the relative ages of the fine-grained basic dykes, the acidic fine-grained dykes and the South-east granite. Particularly good examples of mica-lamprophyre dykes are also present. Raised beach and head deposits, exposed in cliff sections, are fairly similar to those seen elsewhere on the Island, but the accessibility and safety of the site increases their value. The morphology of the coastline reflects the underlying geology, and this is the reason that the castle is located here.

Raised beach and head deposits, exposed in cliff sections, are fairly similar to those seen elsewhere on the Island, but the lower part of the head sequence, preserved in gullies on the foreshore, has been shown to preserve at least two separate Middle Palaeolithic activity areas marked by the presence of stone artefacts. The accessibility and safety of the site increases its value, but this accessibility, combined with active coastal erosion, puts the archaeological record at risk.

Assessment of Site: Current Site Usage	
Community	Mont Orgueil Castle is one of the most well-known and visited tourist sites in Jersey. Cafés and toilets can be found in the village of Gorey and within the castle. It is thought that locals and visitors explore the foreshore around the castle headland, particularly in the summer months. Existing walking and cycling routes pass through the village of Gorey.
Education	The site displays a variety of features. The exposures of granite and the intruding dykes are good and easily accessible, and the cliff sections show good examples of raised beach and head deposits. As parts of the site can be viewed from the castle walls, a geological interpretation board alongside the existing historical boards would likely be well read and might encourage visitors to explore less-visited parts of the site. The site could easily be part of a geological trail, as it is already part of walking and cycling routes around the Island.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Like all coastal locations, the site is subject to high-energy weathering and erosion. The soft Quaternary head deposits infilling gullies in the bedrock under the beach and in the intertidal zone are most at risk, and these deposits do contain Middle Palaeolithic artefacts. However, the bedrock exposures are extensive and fairly robust, and the cliff sections are above the normal high-tide mark.
Potential use	This locality already attracts a large number of visitors and there is much information on the history of the area and historical buildings. It would be nice to complement that information with information on the underlying geology, which has influenced the shape of the coastline, provided natural materials for these buildings and records a much older story of Jersey's past. Interpretation boards could be placed alongside some of the existing historical boards, and the site could easily be part of a geological trail, as it is easily accessible and already on bus and cycle routes. The multiple and varied intrusions would be of interest to members of the public and educational groups alike.

Site Photos:

Photo 1: View looking south-west from the castle walls across Gorey Harbour and the Royal Bay of Grouville. Intertidal outcrops of granite cut by minor intrusions can be seen in the foreground. The granite intrudes the *Jersey Shale Formation* at the south-western end of Gorey harbour in the far distance. © BGS, NERC.

Photo 2: Close-up of the La Rocque granite, which is part of the *South-east igneous complex*, exposed in intertidal areas below the castle. Granite is a coarse-grained intrusive igneous rock that cooled slowly beneath the surface, giving crystals time to grow to a larger size. It is composed dominantly of pink-red feldspar and milky white / grey quartz crystals with some minor amounts of chlorite and biotite. © BGS, NERC.

Photo 3: Fine-grained microgranite pod (beneath the hammer) within paler-coloured South-east granite. © BGS, NERC.

Photo 4: Stringers of dark basic igneous rock within the granite. © BGS, NERC.

Photo 5: Pegmatitic quartz-rich pods, associated with dark finer-grained basic material within the granite. © BGS, NERC.

Photo 6: View looking along a flow-banded rhyolite dyke (foreground), which has cut sub-vertically through the granite. A later, thin, dark grey basic dyke (just above the hammer; trending from right to left across the image) cuts through the rhyolitic dyke. The character of the dyke changes along its length to become broken-up, pale yellow and microgranitic beyond the cross-cutting basic dyke. View looking south-east. This sub-vertical intrusion of acidic magma would probably have flowed along an existing line of weakness in the granite, such as a joint or fracture. © BGS, NERC.

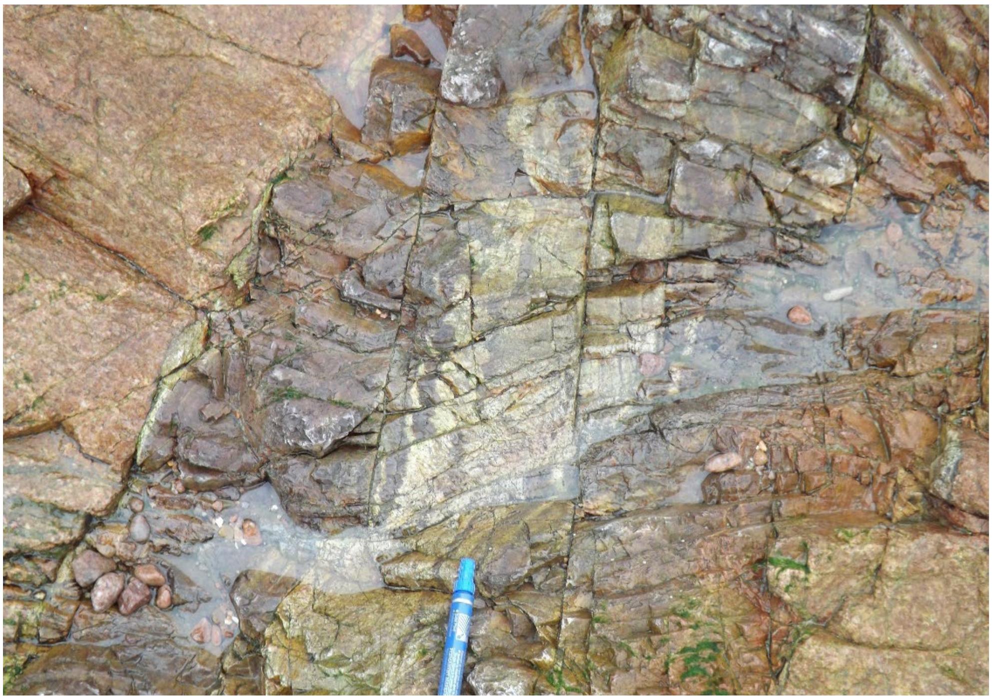


Photo 7: Close-up of the flow-banded rhyolite portion of the dyke. Maroon and white bands within the dyke are sub-parallel to the dyke's chilled margin, where the magma has cooled rapidly against the already cooled and solidified granite.

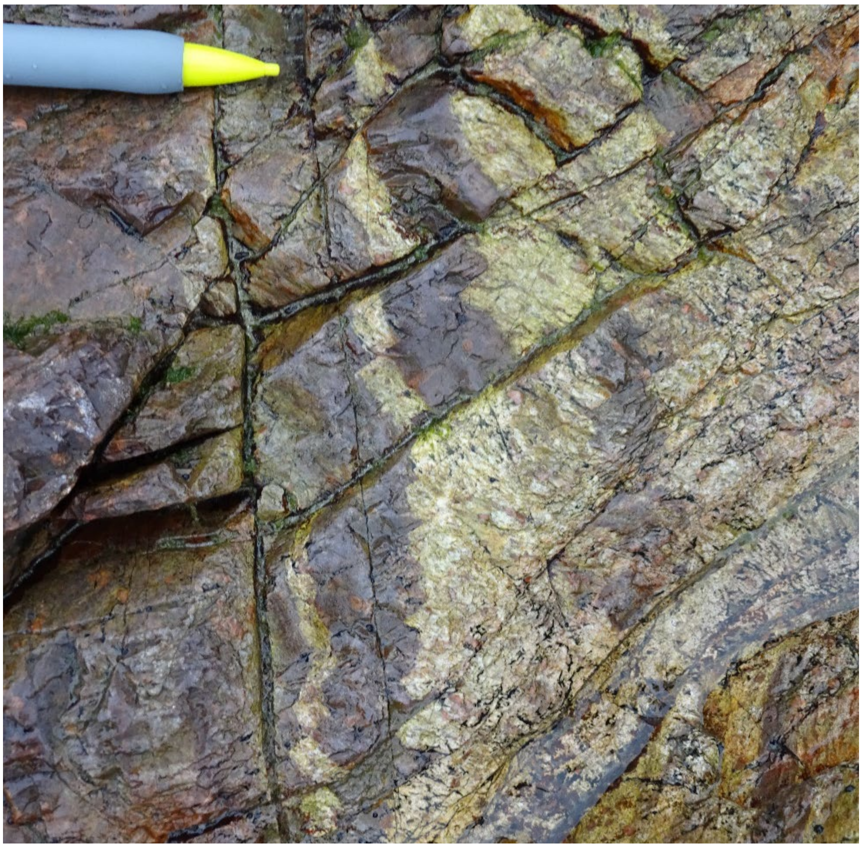


Photo 8: Close-up of flow banding within the rhyolite dyke. The bands have been offset by small-scale faulting.

Photo 9: Photo illustrating the thin basic dyke (running across the image) cutting through the flow-banded rhyolite / microgranite dyke. Both dykes cut through the South-east granite. The cross-cutting contact between the two dykes demonstrates that the basic dyke is the younger of the two, and that both dykes are younger than the granite. © BGS, NERC.

Photo 10: Flow-banded rhyolite dyke near the Gorey Harbour Wall. The dyke is a composite feature with a thin, fine-grained, dark grey basic margin at its contact with the granite. © BGS, NERC.

Photo 11: Close-up of flow banding within the rhyolite dyke. © BGS, NERC.

Photo 12: View along the fine-grained, dark grey, basic dyke, which thins towards the reader and cuts the flow-banded rhyolite dyke (middle of image). Looking north-east. © BGS, NERC.

Photo 13: Close-up of the thin basic dyke, showing thin (cm) chilled margins on both sides that are in contact with the granite. © BGS, NERC.

Photo 14: A dark brown, mica-lamprophyre dyke cutting through the pink granite. This basic igneous dyke is softer than the surrounding granite and has been preferentially eroded more, producing a negative linear feature in the foreshore. Looking north-east. © BGS, NERC.

Photo 15: Close-up of the zonation seen within the mica-lamprophyre dyke. The dyke trends north-east and zonation is parallel to the dyke margins. This sub-vertical intrusion of basic magma would probably have flowed along a line of weakness in the granite, such as an existing fracture. © BGS, NERC.

Photo 16: Sheet-like flakes of mica can be seen glistening within the dark brown mica-lamprophyre dyke. © BGS, NERC.

Photo 17: Close-up of large, bronze-coloured mica flakes within the mica-lamprophyre dyke. These flakes, which are much larger than the surrounding fine-grained matrix, are known as phenocrysts. © BGS, NERC.

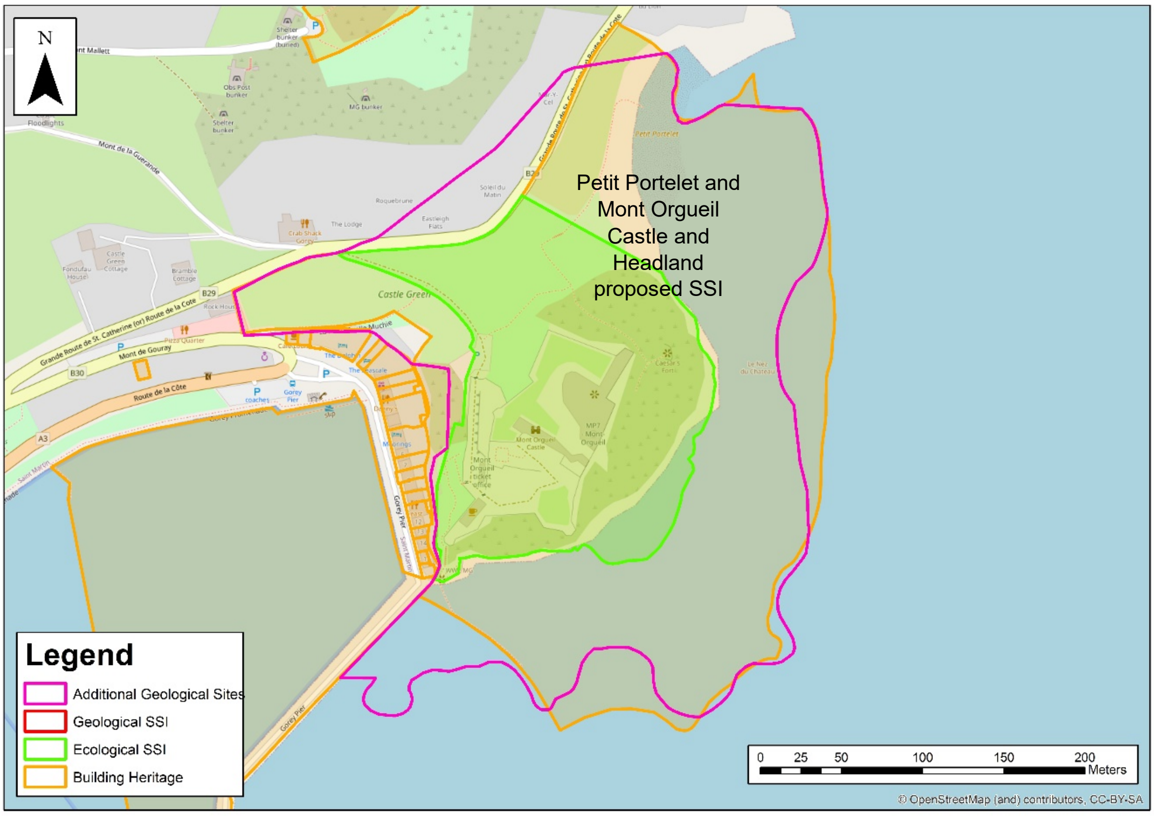
Photo 18: Large mica-lamprophyre dyke intruding granite host rock. The dyke forms a prominent, steep-sided gully in the foreshore exposures north of the castle. Looking north along the dyke. © BGS, NERC.

Photo 19: Section through boulder head below the castle walls. The head deposits appear to infill a former gulley in the rockhead surface. The lower portion of the deposit contains abundant angular blocks of scree, derived from the adjacent fractured granite. A unit of more cobbly head is present in the middle of the section, and finer-grained silty head with a silty loessic matrix is visible near the top of the section. © BGS, NERC.

Photo 20: Section through raised beach and head deposits at the back of Petit Portelet Bay, north of the castle. The section displays raised beach deposits of the 8 m raised beach at the base of the cliff (to the right of the rucksack); they are overlain by up to 4 m of gently dipping loessic head deposits and by overlying boulder-scale head deposits of a similar thickness. © BGS, NERC.

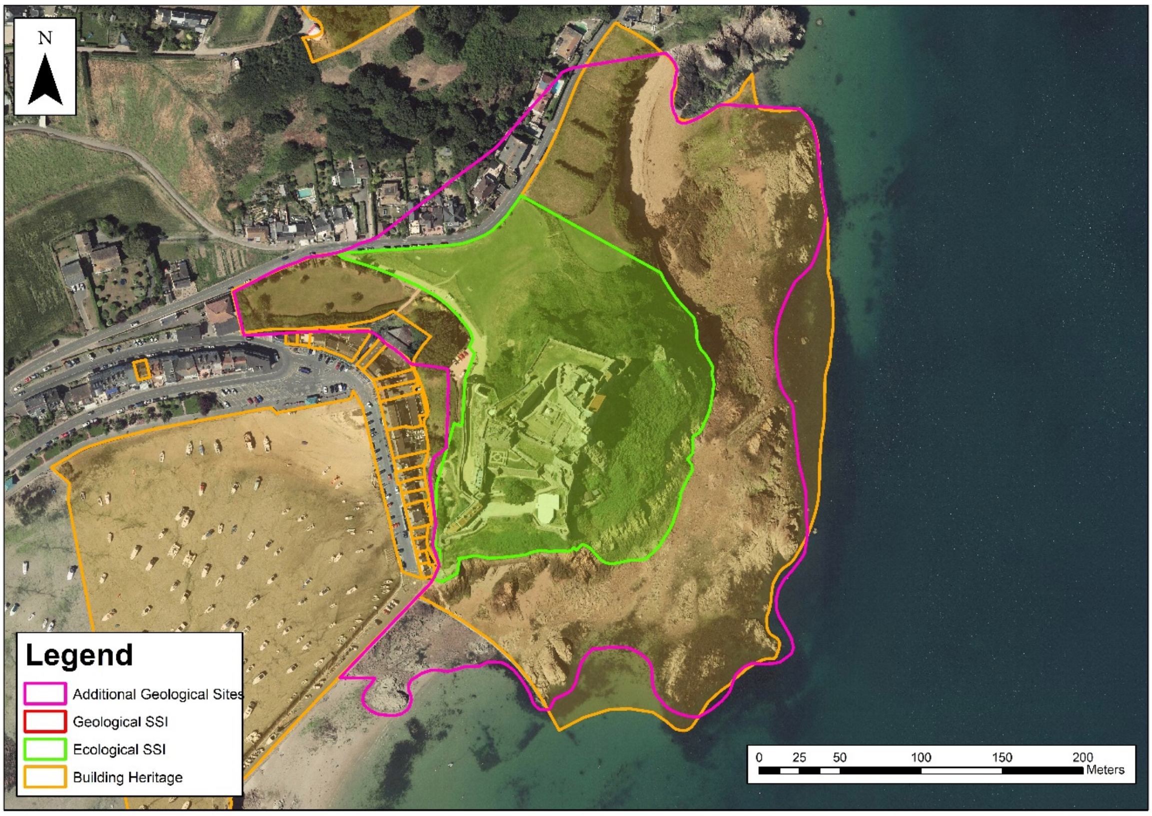
Photo 21: Close-up of the 8 m raised beach deposits at the base of the Quaternary section. The deposit, which is overlain by silty loessic head, consists of well-rounded, clast-supported cobbles and pebbles of coarse- and fine-grained igneous rocks in a matrix of loessic silt. The silt was probably translocated downwards by post-depositional groundwater movement to infill voids in the formerly open-work gravel and cobbles of the beach. © BGS, NERC.

Map of the site boundary on a topographic base



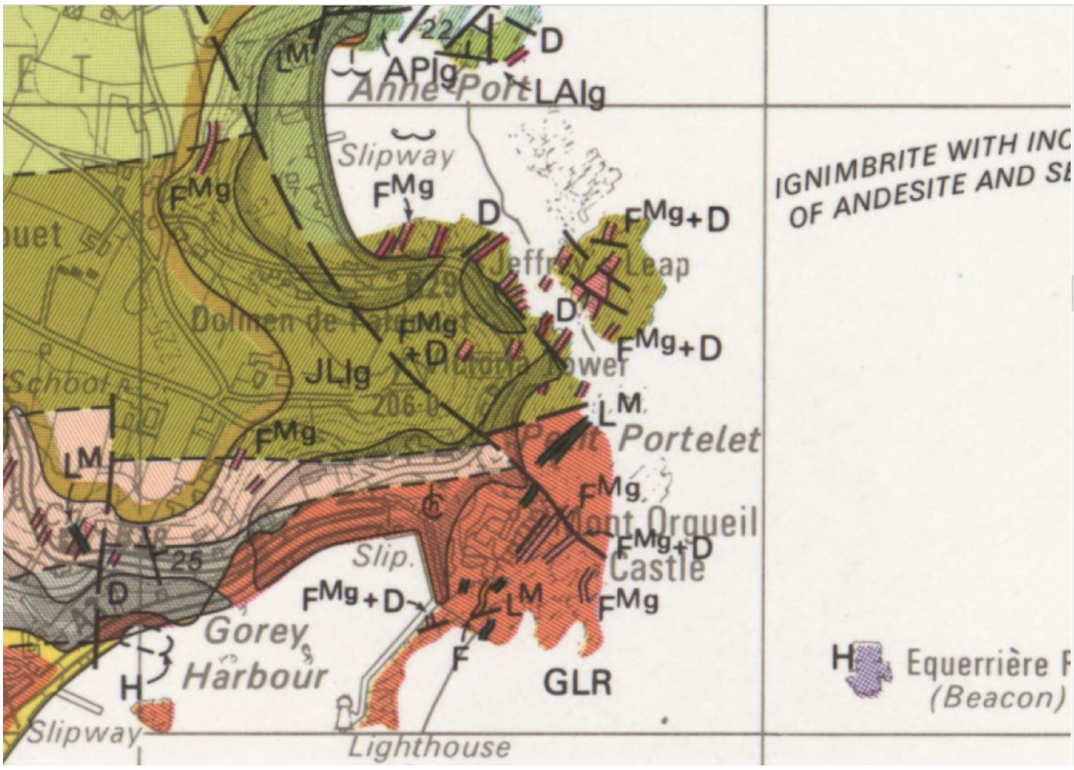
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site

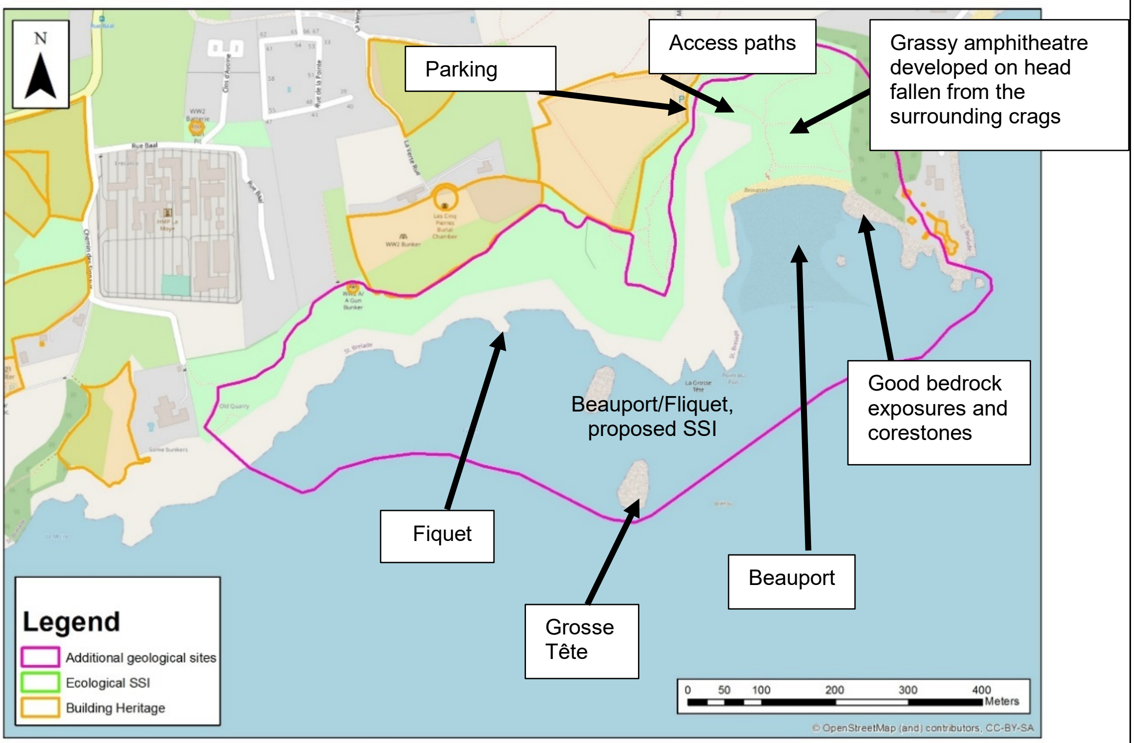


Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

8.10 SITE NAME: BEAUPORT AND FIQUET, PROPOSED SSI

Site Information:	
The site comprises the two adjoining embayments of Beauport and Fiquet. Apart from the extreme south-western corner of Fiquet, the bedrock comprises Beauport aplogranite of the concentrically zoned *South-west igneous complex*; it forms the innermost zone of this complex. The rocks are well exposed along the intertidal platforms and in the surrounding castellated cliffs. Of major interest are the many geomorphological features of Quaternary age, including erosional platforms, deep gullies that are often backed by caves, raised beach deposits overlain by head, including loess lenses, and blown sand. There are several boulder fields on the intertidal platform in Fiquet, and these are notable and unique in Jersey due to the extent of the evidence that they provide of extensive artisanal working for dimension stone from the seventeenth century to the early nineteenth century.	
National Grid Reference: Mid-point: 34489, 64721 West end: 33916, 64614 East end: 34979, 64808	**Site Type:** Natural exposure
Site Ownership: To be confirmed	**Current Use:** Open country, coastal
Field Surveyors: M Gillespie and R Kendall. Additional text and photographs by J and J Renouf (JTR)	**Current Geological Designations:** None
Date Visited: 17 October 2019 and May 2021 (JTR)	**Other Known Designations:** The site sits within Jersey National Park.

Site Map



Stratigraphy and Rock Types:	
Age: Ediacaran (late Precambrian)	**Formation:** *South-west igneous complex*
Rock Types: Microgranite	
Age: Quaternary	**Formation:** Not applicable
Rock Types: Raised beach deposits, head, loess, blown sand, boulder fields, jointing	

Site Description:

Introduction

The site encompasses scenically attractive adjacent bays that include a sandy beach and rock platforms (Photos 1 and 2) and notable features of interest within the bedrock geology, the superficial (Quaternary) geology and the geomorphology.

Background

South-west igneous complex

The *South-west igneous complex* is one of three major intrusion complexes in Jersey. Three main components are distributed in a concentric pattern (IGS, 1982). There is an outer zone of coarse-grained *Corbière granite*, which is the most extensive component and makes up around 80% of the onshore outcrop; it is followed by a middle zone of porphyritic *La Moye granite*, which is roughly 250 m wide. Finally, there is a fine- and uniform-grained central zone of *Beauport granite.* The pluton apparently consists almost entirely of granite (no mappable occurrences of mafic rock or rocks formed by the mingling of basic and siliceous magmas have been recorded), and in this respect, it differs from both the *North-west igneous complex* and the *South-east igneous complex*.

The geometry of the bullseye pattern would suggest that around half of the outcrop of the *South-west igneous complex* is on land, with the other half lying offshore; on this basis, the outcrop of the whole pluton would be around 8 x 5 km. However, granitic rocks crop out on the seafloor for a considerable distance to the south of the south-west Jersey coast (BGS, 2000), suggesting that at least one other contiguous, and perhaps related, pluton lies offshore to the south of the *South-west igneous complex* (Figure 1). The offshore outcrop of intrusive igneous rocks actually extends unbroken along the entire south coast of Jersey, suggesting that the *South-west igneous complex* and *South-east igneous complex* are part of the same large outcrop of intrusive igneous rocks (Figure 1).

A well-defined U-Pb zircon age of *c.* 580 Ma for a sample of *Corbière granite* from a disused quarry north of La Cotte, on the east side of Ouaisné (Miller *et al*., 2001), confirms that the *South-west igneous complex* was emplaced during the Ediacaran Period (the youngest period of the Precambrian Era).

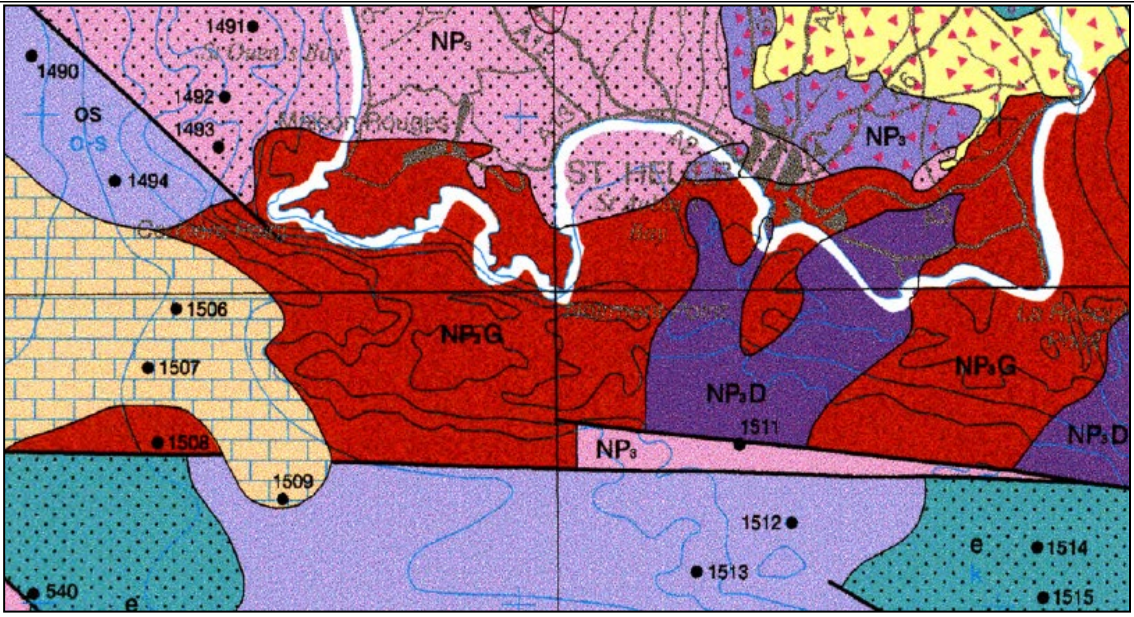


Figure 1. Map of onshore and offshore bedrock geology around the southern half of Jersey (coastline in white) showing the apparent offshore continuation of the *South-west igneous complex* and *South-east igneous complex*. From BGS (2000).

Bedrock Features

Most of the bedrock exposed at the site is *Beauport granite*, the innermost unit of the concentrically zoned *South-west igneous complex*. The rock is well exposed in cliffs and on all the intertidal platforms in both embayments.

Beauport

At the south-western corner of Beauport (Photo 4), emplaced into the granite is a complex, very fine-grained dolerite/basalt dyke: it is so fine-grained that it should strictly speaking be called a basalt. The dyke differs from the numerous east-to-west-striking members of the dolerite dyke swarm that characterise the south-west coastal cliffs from La Corbière to Noirmont, because it is aligned roughly north-south. Its intrusive style is also interesting; it appears to comprise not one dyke but many (Photo 4). However, a closer examination of the occurrences shows that all of the different dyke lengths – which thin and thicken in a bewildering way – are all part of one intrusion. The different parts of the dyke can be traced southward through the castellated granite to the point where they emerge on the south-facing indented cliffs of the eastern extremity of Fiquet (Photo 5). The pattern of intrusion is intimately linked to the jointing system over the whole of the two embayments, which is not just the usual simple dominant three-fold orthogonal form; instead, it is a very irregular, pervasive, three-dimensional alternation of relatively close-packed joints with more widely spaced joints. It should be stressed that these alternations occur not just in horizontal space but also in vertical space. In terms of practical physical expression, the striking castellation of this south-west corner of Beauport (Photos 4 and 5) results from a three-fold set of processes: original joint formation within the cooling granite magma, an extensional tectonic regime of unknown age allowing dyke intrusion and much more recent differential erosion related to weaknesses linked to both joints and their associated dykes. This geomorphology is exceptional in Jersey. A narrow dyke on the same trend occurs in a gully some tens of metres to the west, and its formation is probably linked to the main dyke.

Very accessible exposures of the Beauport granite occur on the extensive rock platform on the east side of the bay. The rock here consists of essentially homogeneous, brick-red to orange microgranite (Photo 6) in which close inspection reveals scattered phenocrysts of quartz and feldspar.

These exposures present good examples of partly formed corestones, which are near-spherical, boulder-sized blocks of rock (Photo 7). Corestones typically form when fractures in the rock are broadly evenly spaced and intersect each other at roughly right angles, thus dividing the rock mass into rectangular- to cube-shaped blocks. Corestones typically develop in igneous rocks (especially granite), because these rocks are often relatively homogeneous to begin with (unlike sedimentary rocks, which contain bedding planes). While they are still well below the ground, chemically active waters move through the fractures, causing the rock on either side to become altered and thus weakened. The effectiveness of the alteration is greater where two fractures intersect near the edges of a rock 'cube', and it is greatest where three fractures intersect at the corners of a 'cube'. Conditions favourable for this type of alteration existed during the early Cenozoic in Armorica, when the region lay near the tropics and the hot climates caused deep-seated penetrative chemical changes. When uplift and erosion bring the rock to the surface, the zones of altered rock are removed by erosion and the 'cube' starts to become a sphere, i.e., a corestone.

Fiquet

The Beauport granite variety of the *South-west igneous complex* forms all of Fiquet except the last few hundred metres of the south-west corner, where La Moye porphyritic granite occurs. The same basic orthogonal jointing has developed here, with the same three-dimensional pattern of relatively close joints alternating with clusters of more widely spaced joints. There is very little variation in the composition and fine-grained texture of the granite. Rock heads on the extensive rocky intertidal rock platform and along the base of the cliffs generally have relatively widely spaced jointing, which is the origin of their resistance to marine erosion. Some of the many gullies appear to be directly related to closely spaced joints, although some may also be associated with faulting.

At the eastern end of the bay, there are two very prominent stacks that rise to a considerable height. The outer stack, named Grosse Tête, is well separated from the adjacent stack by a rock platform of marine erosion (Photo 8), a dissected remnant of the 8 m marine platform formed during the last interglacial high sea level (Ipswichian/Eemian).

Towards the middle of the bay, there is a promontory (Photo 9), which is notable for its strong jointing pattern and the undercutting by the sea of one particularly large, flat-lying jointed slab, which forms a natural arch of great beauty when it is filled with calm water by an incoming tide (Photo 10). Some of the boulders on the foreshore in the south-western corner of the bay are waste stone from a quarry that operated for some years after the Second World War.

The Quaternary development of Beauport and Fiquet

In general, the geomorphological profile of Jersey, whether from N–S or E–W, is expressed in a three-fold sequence consisting of (1) a high composite plateau, which is everywhere above 50–60 m; (2) steep coastal slopes with dips in the mid-20^0 range, except where they are wholly made of exposed rock, in which case they are vertical; and (3) a low-lying plain extending out from the base of the slopes/cliffs and forming the bed of the Normanno-Breton Gulf. The origin of this pattern lies millions of years in the past. In terms of Beauport and Fiquet, both bays show local examples of the three-fold division, with flat plateaus dropping precipitously down steep vegetated coastal slopes or vertical cliffs to the intertidal platform (Photos 1 and 2).

Over the past half million years, a series of five 100 ka climatic cycles have affected the Earth, and they are characterised in our region of the Normanno-Breton Gulf by up to 100 m changes in sea level compared to that of today; these changes are associated with an underlying erratic but overall rise in the land of 8 mm a century on average through tectonic forces. Each cycle comprised a high sea level during interglacial warm periods followed by a cold stage when water was abstracted from the sea and was moved by the prevailing winds of the time to the poles, where it was precipitated as snow. The snow accumulated to form great ice sheets, and the water taken from the oceans resulted in the sea level falling by up to 100 m. Extremely cold conditions were part of the extremes of each cold stage. While it was not ice-covered, Jersey did not escape this cold or the drops in sea level, which led to the island becoming a flat-topped plateau in the middle of a tundral plain.

During the part of the Quaternary leading up to the last interglacial (see below), a series of past sea levels stood at heights of up to 40 m and more above the present sea level (Renouf and James, 2010), and the erosion associated with these sea levels is responsible for the shaping of the bay-head form of the Beauport embayment; this erosion steadily cut it back at lower and lower levels until it was more or less filled by the most recent deposits (see below).

If the high sea level of the last interglacial (126 to 115 ka BP, known as the Ipswichian in Britain and as the Eemian on the Continent) is taken as the departure point for this account, then the evidence can be seen all around. The sea level is known to have been 2 m higher than the present-day sea level (Renouf and James, 2010), and the remnants of the rocky platform, cut by the winds and tides of the time, are mostly found in the higher rocky zone at the base of the present cliffs and slopes, well picked out by the black lichen zone of *Verrucaria maura* (Photos 1 and 2). At the back of this high-level platform, at about 8 m OD, there are occurrences of the cobble beaches that formed at the highest tide levels of the times. Such a remnant beach can be seen at the eastern end of Fiquet (Photo 11), but such beaches are not prominent in either Beauport or Fiquet.

Following the end of the interglacial, the climate overall cooled over the next 85,000–95,000 years to a maximum cold level between 26 ka and 15 ka. There were both temperate and very cold spells of several thousand years preceding the maximum cold level. The sea was nowhere in sight; it had retreated well out into the Western Approaches of the Channel. Both temperate and cold climate weathering occurred everywhere, and the abandoned cliffs and coastal slopes of Beauport and Fiquet accumulated substantial wedges of angular rocky sediment known as head, as a result of freeze-thaw endlessly breaking off rocks, which fell due to gravity to lodge below. A predominant yellowish/orangey tint of the resulting head is caused by the infiltration of fine dust particles, known as loess, that were transported on powerful winds blowing out from the cold north of the ice sheet margins – very approximately on a line from the Wash to South Wales.

The head accumulated on whatever surface lay at the bottom of the cliffs and steeper coastal slopes, and, where cobble beaches existed, these too were buried by the head. The best places to see the head are above the present-day cobble beach of Beauport and backing the intertidal platform of Fiquet. Of particular significance in this context are the head cliffs at the eastern end of Fiquet immediately opposite the near stack. Here, huge, rounded boulders (Photo 11) of the last high sea level have been buried beneath the head derived from the impressive crags above; they are being eroded out by present storm action and even more by the active erosion of the head in which they are embedded.

Artisanal economic activity

On both the eastern and western sides of Beauport, where large boulders (maximum dimension of greater than 30–50 cm) are present, mason's marks occur, indicating stages in the process of splitting rock for dimension stone. There are up to a dozen such boulders in Beauport, but far greater numbers of boulders occur in boulder fields in the majority of the many gullies in Fiquet. There are many variations in the nature of the mason's marks and it is certain that those cut by flat-ended chisels (cf. the Cape chisel, Gage and Gage, 2002) represent particular time periods from the 17th century to the early 19th century; round holes and the fewer triangular ones result from the use of handheld drills (a two-man operation) and machine drills and are mainly from the 19th century and later. Rybot (1947) describes an Island-wide distribution of these intertidal boulders being worked for dimension stone and shows some of the variations in technique to be found, but, though he mentions that such boulders occur along the cliffs of south-west Jersey, it is not clear if he was aware of the rich boulder fields of Fiquet. Photos 12A to 12D illustrate some examples. A full study is needed to document the variety and abundance of these worked boulders and to make comparisons with reports from beyond Jersey; the New England publication by Gage and Gage (2002) is indispensable.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Public road to parking area (Beauport Beach parking)
Access	Beauport Beach is accessed from the parking area by a path with numerous steps. The height difference between the parking area and the modern beach is around 50 m. This is also the height difference for the climb down to Fiquet, but the next section sets out the safety issues.
Safety of access	For Beauport, the path requires a moderate degree of fitness and balance. The last section of steps down to the modern beach is steep, although it does have a handrail. The beach and most of the bedrock outcrop are in the intertidal zone, so they are prone to tides and waves. At low tide, the beach provides easy access to the intertidal platform on both flanks of the bay. For Fiquet, the same height difference exists when descending from the plateau at the headland south of the parking area, but the rough path down is only recommended for those at ease with steep and dangerous descents.
Safety of exposure(s)	The main exposures in both bays are in the intertidal zone, formed of a rough, rocky platform and intervening gullies that are exposed to tidal constraints, wind and waves. There is no path on the platform, and the rocks here may be slippery with many trip hazards; a mild to middling level of scrambling is required to access some parts. The exposed Quaternary deposits of head can be viewed safely in both bays from the tidal platforms.
Current conflicting activities	None
Restricting conditions	The bedrock exposures are mainly in the intertidal zone and will mainly be inaccessible above higher mid-tide levels.
Nature of exposure(s)	The best bedrock exposures are large areas of clean, very well-exposed rock, mainly on an intertidal rock platform. The Quaternary deposits, mainly head, are exposed in the back walls of small, recent landslips on the otherwise vegetated modern sea cliffs backing both bays.

Assessment of Site: Culture, Heritage and Economic Value	
Aspect	**Description**
Historic, archaeological and literary associations	Beauport Battery is an example of an early-19th-century fortification (HER Number 0100401; Listed building BR0401). Beauport lithic scatter (HER Number 0100364; Listed place BR0364). Artefact scatter (HER Number 0100429)
Aesthetic landscape	Both bays are scenically attractive, particularly when viewed from the coastal path south of the parking area. In Beauport, the combination of extensive clean sand and upper tidal rounded cobbles set off by the surrounding vegetated coastal slopes and impressive rocky crags is always a delight to see.

History of Earth science	None
Economic geology	Evidence of extensive exploitation of large granite boulders by masons over the past three centuries

Assessment of Site: Geoscientific Merit				
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta	Local	Local		X
Structural geology	Local	Local		X
Palaeontology				
Geomorphology	Local	Regional		X

Geoscientific Value of the Site
A number of noteworthy features can be viewed within a small area at these scenically attractive bays. The site is the unofficial 'type area' of the Beauport granite, which contains some exceptional examples of orthogonal granite jointing and good examples of developing corestones.

Assessment of Site: Current Site Usage	
Community	The modern beach at Beauport is used for typical beach-related recreational activities. Fiquet is a quieter bay that is much favoured by those seeking peace and quiet.
Education	It has long been a site visited by school classes, including for Sixth Form fieldwork.

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	The bedrock exposures are robust. The unconsolidated Quaternary head deposits are vulnerable to erosion and best viewed from the beach.
Potential use	Beauport is very easily and safely accessed and therefore is useful as part of school education for students of all ages. There is plenty of space for interpretation boards that could form a part of a geotrail. Although the granite exposed in the foreshore is of interest for its range of features, it is the variety of geomorphological features, some related to climate change issues both past and present, that makes the bay so useful educationally. Fiquet is not accessible for normal school field studies.

Site Photos:

Photo 1: Looking down and north-east across Beauport to the composite rock platform with, from left to right, the high cliffs (mostly hidden in the trees) that are the source of the head forming the gently shelving 'amphitheatre' and the line of cliffs above the cobbles; the remnant dissected 8 m rock platform (black passing up to pale grey); the present tidal platform with good detail of the Beauport granite; many examples of incipient corestone formation beyond on the rising black outcrops; and the isolated stack. Courtesy of JTR archive, May 2021, P5300412, Beauport/Fiquet.

Photo 2: The Fliquet intertidal zone from the eastern end of the bay with scattered boulder fields extending to just short of the far headland. There are a considerable number of boulders with mason's marks, and these show a range of techniques. The massive, near-vertical crags are all developed in Beauport granite with the orthogonal jointing that is such a strong feature of all its outcrops. There is a very fine natural arch in the south face of the central crag. Courtesy of JTR archive, 14 Feb. 2020, P2140024, Beauport/Fiquet.

Photo 3: Looking north-west from the exposures of the Beauport granite forming the present intertidal platform. Remnants of the dissected last interglacial marine platform are seen immediately below the bushy trees (top right) on the eastern side of the bay. Beyond this is the modern cobble-backed sandy beach and backing head cliffs. The visible part of the low-dipping grassy amphitheatre defines the surface of cold stage head accumulation with an overlying veneer of blown sand. BGS © UKRI 2020.

Photo 4: An extremely rare example of a N–S-trending basic dyke in Jersey. This N–S-trending, fine-grained, dolerite/basalt dyke is found in the south-west corner of Beauport. Though they appear to be separate dykes in the photo, the many outcrops at this locality anastomose in a complicated fashion and can be considered one dyke complex. See also Photo 5. Note the partly hexagonal-style jointing at right angles to the dyke margins. Courtesy of JTR archive F1, 27 May 2021, P5270213, Beauport/Fiquet.

Photo 5: The prominent castellated crags defining the south-west corner of Beauport as seen from a drone looking northward into the bay. The striking view aside, the three crags and the two gullies to the left are defined by the anastomosing dyke members coming through from the dyke, as shown in Photo 4. The three major orthogonal joints (N–S, E–W and subhorizontal), together with the dyke elements, define the overall form of the crags, but the joints vary in strength and spacing, which is compounded by the presence of zones of variably orientated, impersistent, closely spaced joints. Courtesy of Paul Lakeman archive, F1, 2021, DJI_0175jr, Beauport/Fiquet.

Photo 6: Rounded, partly formed corestones in Beauport microgranite on the intertidal rock platform forming the east side of Beauport Bay. These structures form in two stages: initially, in the subsurface, by chemical alteration around fractures, and subsequently, at the surface, through the weathering and erosion of the altered rock. Pen for scale. BGS © UKRI 2020.

Photo 7: Brightly coloured rocks produced by chemical alteration around fractures seen in Beauport microgranite on the east side of Beauport Bay. Unaltered microgranite is light grey, while the pink and orange colours are different types of iron-rich minerals produced when oxygenated groundwater circulated through thin fractures in the rock. The pink mineral is probably hematite (Fe_2O_3) and the orange mineral is probably goethite (FeOOH). The goethite appears to have overprinted the hematite, suggesting that the hematite was produced in an older alteration event and the goethite was produced in a younger (possibly ongoing) event. Pen for scale. BGS © UKRI 2020.

Photo 8: Two stacks closing off the eastern end of Fiquet. Between the outer stack on the right, Grosse Tête, and the inner stack on the left is the linking, eroded-down remnant of the 8 m Ipswichian/Eemian marine platform; the top of this platform lies at roughly the level between the upper edge of the black *Verrucaria maura* and yellowish *Xanthoria parietina* lichen zones. In the middle distance is the slightly sloping platform of marine erosion linked to the present tidal regime. Courtesy of JTR archive, 27 October 2020, P3290043, Beauport/Fiquet.

Photo 9: The prominent crag in the centre of Fiquet from the west, with the small-seeming gully on the right leading left to the natural arch (Photo 10), which can just be made out above the water in the gully. The origin of the arch is linked to low-dipping (right to left), widely spaced joints below the prominent 'gash' with white staining. Courtesy of JTR archive, 2011, P3290043, Beauport/Fiquet.

Photo 10: Photo x14: Looking out seaward at low tide from beneath the natural arch at Fiquet. Courtesy of Jonathan Renouf archive, May 2021, IMG_1884, Beauport/Fiquet.

Photo 11: Head at the eastern end of Fiquet rests on the 8 m rock platform (below angular rocks) and rounded boulders related to this platform and the Eemian interglacial sea. The large sub-rounded boulder in the foreground is in the process of emerging from beneath the cold stage head through the erosion of the head in which it is embedded. The positioning of the pale orange area on the boulder above the irregular dark patch has just recently been exposed. Courtesy of JTR archive, 27 May 2021, P5270349, Beauport/Fiquet, with permission.

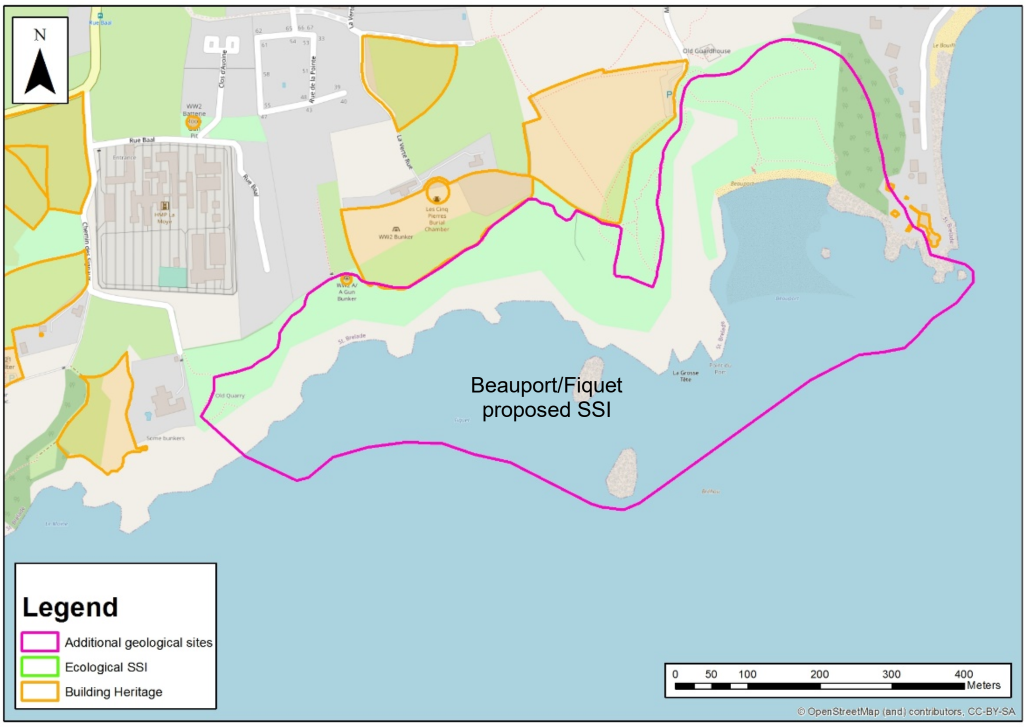
A

B

C  D 

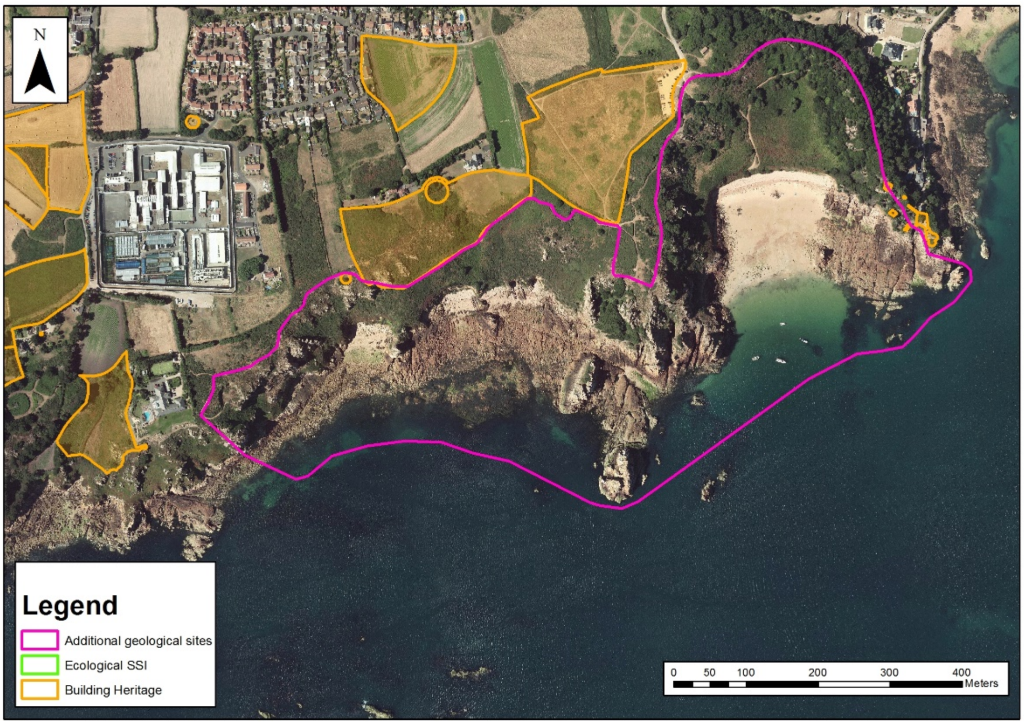
Photo 12: A sampling of mason's marks on boulders at Beauport and Fiquet. **12A:** Fiquet boulder showing a block split off on the left via a long slot on the main boulder and a similar slot in preparation for a second split in the middle of the same boulder. Technique: Flat wedge continuous. **12B:** Continuous beginning slot for splitting of large boulder. Note the double slot, which represents the chisel marks addressed from both sides, leaving a distinctive ridge down the centre. **12C**: Boulder from Fiquet. One half of a boulder split using the spaced wedge and slot method. Scale in cm. The lithology is unusual for Fiquet and represents a partially absorbed enclave of intermediate composition within the Beauport granite. **12D:** A large boulder from Fiquet, most likely centre drilled using a two-man team, with one holding the bit in place and the other wielding a sledgehammer. The hole is sub-triangular in cross section because of the hand rotation of the bit between blows. It is not readily seen here, but the resulting angle produced in the boulder is obtuse – much greater than 90 degrees. This process was the first stage in reducing the size of the boulder to more manageable proportions. Courtesy of JTR Archive, A: PA 170167 2020, B: PA170162 2020, C: PA020673 2011, D: PA170082, Beauport/Fliquet, with permission.

Map of the site boundary on a topographic base



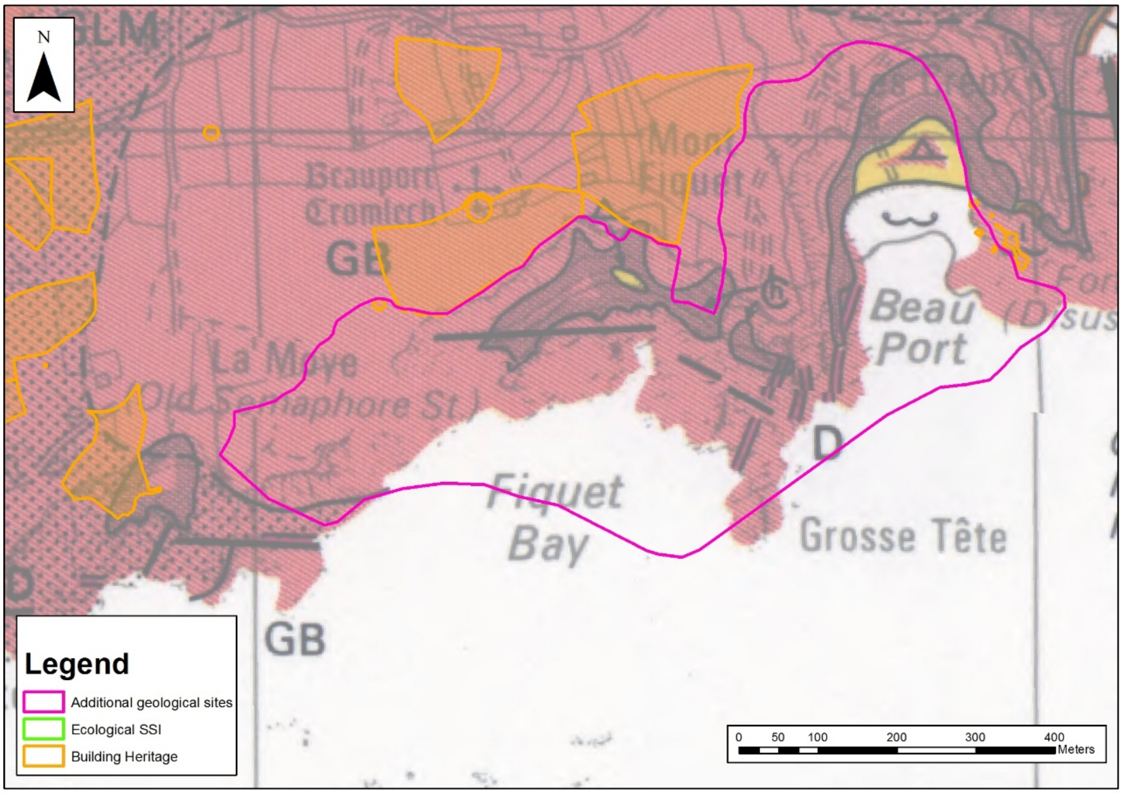
Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph



Imagery ©2020 Government of Jersey.

Published geological map of the site



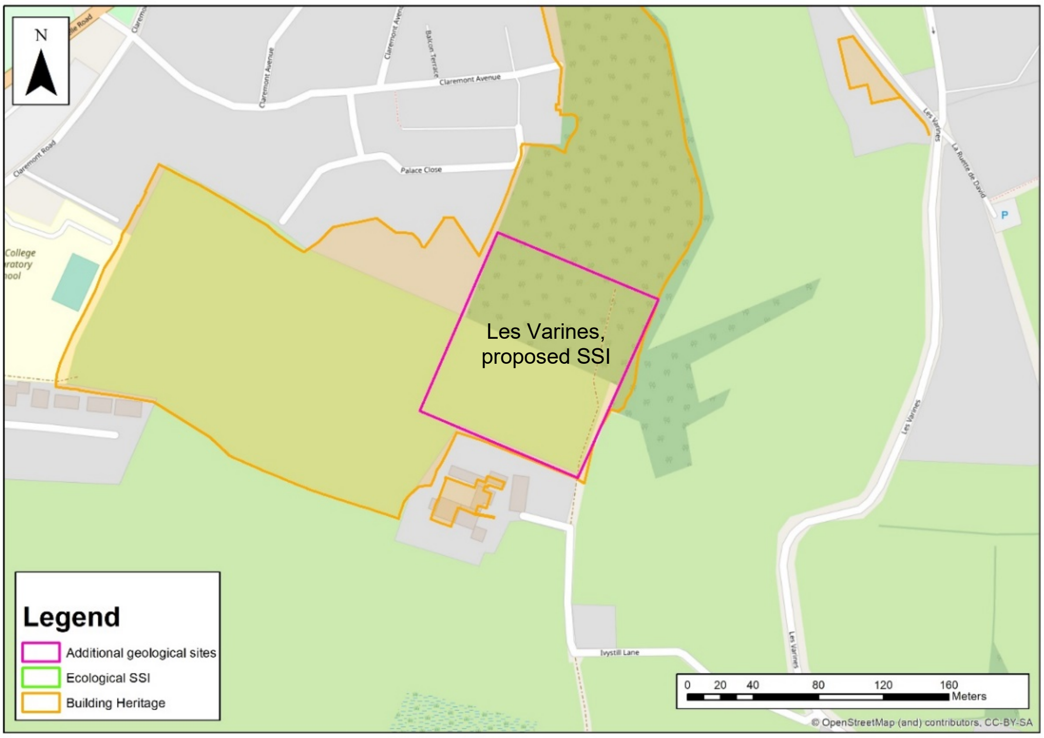
Reproduced from IGS (1982), which should be referred to for further details. Grid squares are 1 km on each side.

8.11 SITE NAME: LES VARINES, PROPOSED SSI

Site Information:
Les Varines is an internationally important site preserving 15,000-year-old Magdalenian structures, pits, hearths, artefacts and artwork. A geophysical survey indicates that the sedimentary sequence at Les Varines is complex, and sediment accumulation in the vicinity of the site probably began during the Middle Pleistocene with the creation of coastal features during several high sea-level events. The geomorphological context of the site is a cove and cliff topography in which colluvium appears to be banked against a former cliff. The Upper Palaeolithic site sits on a saddle of land between a Middle Pleistocene granite cliff and a rocky outcrop that was once a sea stack. The granite features that compose the catchment are infilled with and masked by head deposits, and they are constrained to the north-east and south-west by valleys (Conneller *et al*., 2016).

National Grid Reference:	**Site Type:**
Mid-point: 43509, 65709 West end: 43438, 65675 East end: 43585, 56743	Manmade artefact (now buried)
Site Ownership: To be confirmed	**Current Use:** Agricultural land
Field Surveyors: M Pope and M Bates	**Current Geological Designations:** None
Date Visited: This site was not visited by BGS.	**Other Designations:** Built Heritage: Les Varines

Site Map



Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Stratigraphy and Rock Types:	
Age: Pleistocene	**Formation:** Head deposits
Rock Types: Head deposits comprising loess, redeposited loess, granitic sand and loess and Holocene hill wash. Locally up to >8 m thick	
Age: Pleistocene	**Formation:** Raised beach deposits
Rock Types: Sands and silts from former marine and intertidal deposits deposited in front of a now raised, 18 m cliff line	

Site Description:

Les Varines is the name given to a locality preserving internationally important Upper Palaeolithic remains. It is located in the Parish of St Saviour and covers two different fields on a south-facing slope at the back of a small valley, which crosses the foreshore to the coast 2 km to the south.

The site was probably discovered in the late 19th century, when artefacts consistent with Upper Palaeolithic technology were collected from 'Bagatelle Fields', but the site was not properly discovered until the mid-1990s, when Peter Bohea recorded a scatter of white patinated flint in the lower field.

A team from the British Museum, Newcastle University and the UCL Institute of Archaeology investigated the site between 2010 and 2018; they determined that artefacts in the lower field were being brought to the surface by plough action from head deposits comprising redeposited loess and fine granitic sand. Moving into the adjacent upper field, the excavations revealed *in situ* evidence of a Magdalenian camp. Abundant flint artefacts, including backed projectile points, hearths, pits and engraved microgranite plaquettes comprise a complex and important record. On the basis of the artefact types and OSL dates from the head deposits, the site is considered to date to around 15,000 years ago. The full limits of the site and associated deposits have not yet been fully mapped, but more than one horizon of occupation has been recorded at the site, and the head deposits overlay much older marine deposits that might relate to the 18 m raised beach.

The site shows the rich potential of deposits mapped as head on the Island. This internationally important archaeology was only revealed here through ploughing.

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	No close public road access
Safety of access	No clear footpath access
Safety of exposure(s)	Not applicable
Access	No public access
Current condition	Under plough or vegetation
Current conflicting activities	Agriculture
Restricting conditions	None
Nature of exposure(s)	Plough soil on part of the site

Assessment of site: Culture, Heritage and Economic Value	
Aspect	**Description**

Historic, archaeological and literary associations	Les Varines is an Upper Palaeolithic occupation site dating from towards the end of the last cold stage; it was possibly occupied by people of the Late Magdalenian culture (HER Number 1100318; Listed place SA0318). Vale View Farm is an historic farm group with 17th-century origins (HER Number 1100053; Listed building SA0053).
Aesthetic landscape	View over the coastal plain and southern coast toward Les Miniquiers
History of Earth science	None known
Economic geology	None known

Assessment of Site: Geoscientific Merit

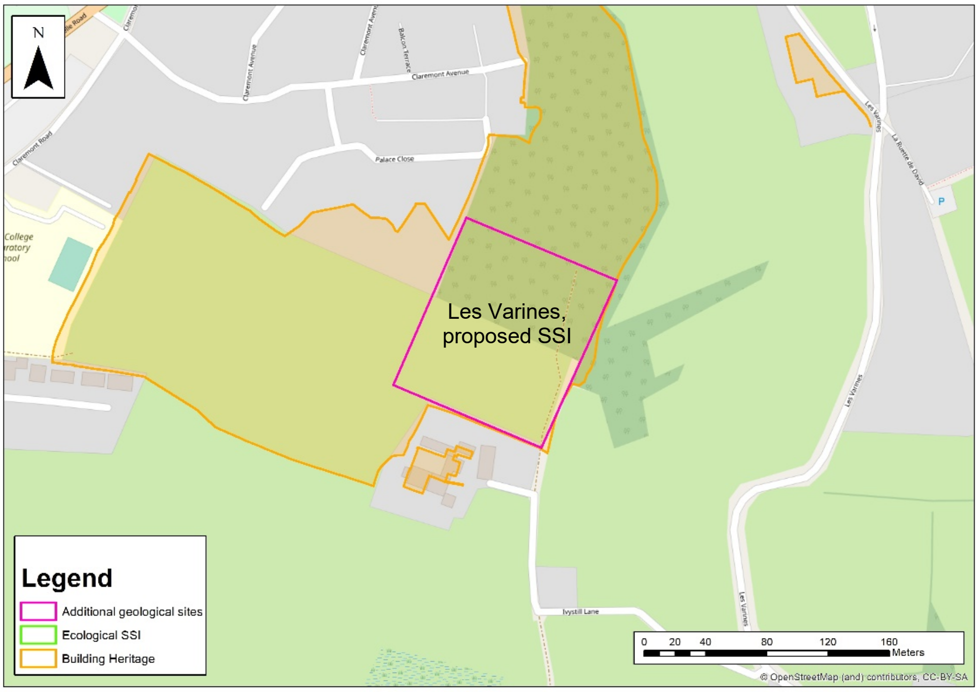
	Rarity	Quality	Literature/collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/mineral/meta				
Structural geology				
Palaeontology				
Geomorphology				
Prehistory	International	Excellent	Detailed	X

Geoscientific Value of the Site

The site contains a sequence that is internationally important for understanding cold stage environments and human occupation.

Assessment of Site: Current Site Usage	
Community	Not used
Education	Not used

Assessment of Site: Fragility and Potential Use of the Site	
Fragility	Very vulnerable to rooting and ploughing
Potential use	Landscape interpretation

Map of the site boundary on a topographic base
 Topographic map © OpenStreetMap (and) contributors, CC-BY-SA.

Map of the site boundary on an aerial photograph
 Imagery ©2020 Government of Jersey.

Appendix 1 Additional sites identified in literature and from conversation with local experts

During this study, a number of sites and features of interest were suggested by local experts. Many of these suggestions are included in the new sites proposed by this report. With additional research, these sites could be added to the list of protected sites, form additional ‘2nd Tier’ sites or provide a basis for further research.

Suggested additional sites from Paul Chambers (please note that some are offshore):

- Seymour Tower (layered diorite, batholith stopping and Pleistocene sediments)
- Les Maisons (sheeted pegmatite/microgranite complex and folding)
- Les Écréhous (peat deposit near Tas de Pois)
- Maîtresse Ile (ancient migmatic lens below the flagpole)
- Les Pipettes (‘the great Channel Islands dyke’)
- Pontac / Le Hocq (Jersey Main Dyke Swarm)
- La Rocque (granite and examples of historical quarrying and stone use near the harbour)
- Creux Gros and other large caves off the north coast
- Grosnez (several topographic and landscape features)
- Plémont / Grève au Lançon (caves, Needle Rock)

Suggested additional sites from J Renouf:

- Plémont (evidence of sea-level changes)
- Grève au Lançon (readily accessible examples of a stage in the erosional development of Jersey bays [Renouf and James, 2005])

Potential additional sites and points of interest extracted from Ralph Nichols' website (http://www.jerseygeologytrail.net/):

Location	Geological features
Archirondel, La Mare Sainte Catherine / St Catherine's Bay	At the southern end of St Catherine's Bay, above the sea wall, there is evidence of a raised beach that formed during the last interglacial, when the sea level was ~8 m higher than it is today. It sits on eroded rhyolite bedrock, which formed in episodes of volcanic activity during the Ordovician. The raised beach is overlain by loess and possible head deposits, which accumulated during the last glacial period.
Le Malade, St Catherine's Bay	At the small headland – Le Malade – flow-banded rhyolites outcrop on the beach. They have streaked ignimbrite intervals, breccia beds, tuffs, flow-folded intervals and occasional spherulites. At the headland itself, the remains of a lamprophyre dyke have eroded to form a channel along the beach that is approximately 1 m wide. Just past the headland there are outcrops of yellow-brown silts, clays, sands and grits. These outcrops are possibly preserved in the eroded junction between the Bouley Rhyolite and the Rozel Conglomeration formations.
Le Houguillion, St Catherine's Bay	Towards the northern end of the bay, past the slipway at St Catherine's Tower, is Le Houguillion. Pebbles, potentially representing a flash flooding event, are found along with outcrops of shale and rhyolites resting on the Rozel Conglomerate, which formed during the Silurian. In places, the Rozel Conglomerate has eroded into hollows, which contain raised beach deposits similar to those in the south in the bay. The mixed head and dark grey soil, including oyster shells and charcoal, are thought to have slumped down onto the beach deposits when the road was built above this site.
Le Saie Harbour	Along the coast from the slipway towards La Coupe Point, dolerite dykes have intruded into the *Rozel Conglomerate Formation*. A raised beach can also be seen at the base of the cliff. Just past La Coupe Point, mica-lamprophyre dykes also intrude into the conglomerate.
Les Hurets Crags, Bouley Bay	Les Hurets are an outcrop on a ridge above Bouley Bay with the remains of a former guardhouse. There are outcrops of flow-banded rhyolite, agglomerate and spherulitic rhyolite.
Côtil Point, St John's coastline	Côtil Point is a wave-cut platform with narrow inlets eroded into it. A perched stack and a cave here represent a time when the sea level was ~8 m higher than it is today. At the bottom of the steps, there are exposures of Mont Mado aplogranite from the North-west granite. It has small uniform quartz and feldspar crystals and thin films of muscovite mica along its joint surfaces. Outcrops of Bonne Nuit Ignimbrite from the St John's Rhyolite Formation can be seen at Côtil Point itself. Bonne Nuit Ignimbrite is grey to light brown with a streaky texture. At the back of the second inlet, the junction between this granite and the older St Saviour's Andesite can be seen. The andesite is medium grey with pink-red feldspars, and has been intruded by dykes, veins and a thick aplite sill.
Grève au Lançon Côtil Point, St John's coastline	This bay's granite cliffs are part of the North-west granite complex. They contain large orthoclase feldspars, veins, faulting and xenoliths and have been intruded by mica-lamprophyre dykes. Marine erosion, focusing on the relatively softer dykes, fault zones and fault planes, has created caves, stacks, archways and inlets, which are particularly noticeable on the east side of the bay.

	On the west side, a deep gully is being eroded by simultaneous wave and stream action. The remains of a dolerite dyke can be found in the wall, and at the back of the gully under the waterfall, there is a lamprophyre dyke. On the beach, the granite outcrops have speckled diorite and isolated feldspars, which have been incorporated from an older rock during intrusion. Further west, there are two more lamprophyre dykes on the eastern side of a gully: one has undergone faulting and the second may have been intruded into colder granite. More can be observed as one continues west along the beach.
Val de la Mare Reservoir	In the cliffs, on the eastern path by the reservoir, normal faulting has displaced sections of the *Jersey Shale Formation*.
Le Chemin des Creux – private road behind St Brelade's Church	The cliff exposures at the side of the road initially show pink, coarsely crystalline granite, which has been intruded by dark grey dolerite. Further along, there is a potential fault zone that has eroded into a channel about 1.5 m wide. Rounded beach pebbles here suggest that this is a possible raised beach. It is overlain by angular granite pieces within a grit and sand matrix that could be glacial head.
Le Coleron Battery Viewpoint	On the path just before the viewpoint, a deep, narrow chasm has eroded into the cliffs, probably along a tear fault. On the far wall, a nearly vertical dark-grey dolerite dyke is exposed.
St Brelade's Bay Beach	At the south-western end of the beach, a dolerite dyke cuts through the wave-cut platform and into the well-jointed pink granite cliff face. The dyke has small tear faults and may be a continuation of the dyke near Le Coleron Battery viewpoint. Glacial head rests unconformably on the granite's irregular upper surface. South, over Les Fantômes cliffs, three nearly vertical chasms, which are about 2 m wide, have eroded into the granite. There are dolerite dykes in the walls and floors, and their intrusive contacts with the granite are visible. Walking back across the beach towards the slipway, one can see small streams; some of these streams start in the beach itself. These are sourced from water bubbling up through the sands from springs in the granite bedrock underneath the beach.
St Aubin's Bay	This bay has been eroded into the softer rocks of the *Jersey Shale Formation*, and it is flanked by the harder granites of the South-west and *South-east igneous complex*es at either end.
Elizabeth Castle	The castle is built from granite and granophyre quarried from the nearby rocks, which are part of the *South-east igneous complex*.
French Harbour, La Folie	A well-jointed dolerite dyke, part of the NE–SW group of the Jersey Main Dyke Swarm, can be seen intruding the granite bedrock at beach level in the north-east corner wall of the harbour. It is half hidden by masonry and has undergone weathering, which has created pits.
Le Hocq	Dark grey dolerite dykes can be seen here, and in places they have been displaced by faulting. Near Le Hocq Point, there are pink-red La Rocque granite outcrops, and south of the slipway, granite exposures have been intruded by diorite dykes from the Jersey Main Dyke Swarm with an average width of 1 m.
Pontac Beach, St Clement	South-east of the slipway at Pontac Beach, there are several unusual dykes. They are different from other dykes from the Jersey Main Dyke Swarm because they have been altered by low-grade metamorphism. These dykes are made of a black and white speckled crystalline rock and can be described as epidiorites.

Seymour Tower	The littoral zone between Seymour Slipway and Seymour Tower is generally covered by present-day beach sand, but in places a yellow-brown silty clay is exposed. It has formed horizontal deposits on the underlying South-east granite, and the standing pools on the beach indicate that these deposits continue under the current beach. There are similar deposits near Le Hurel Slipway that include possible carbon pieces. Seymour Tower itself is built using granite from the *South-east igneous complex*. Southwards around the coast, there are light-grey consolidated silt and sand beds exposed in the beach south-east of La Rocque Harbour and the stacks L'Angliaiche and Le Teton. These beds lie on granite bedrock; brown patches indicate iron, and clasts within these beds are variable in colour, size and shape. Near the harbour, there is also a potential glacial erratic in the form of large diorite boulders. Two dykes are visible near L'Angliaiche: one of white quartz, up to 1.5 m wide, in the cliff face of a small stack, and a second dyke of mica lamprophyre with clear biotite mica pieces that appears in a shallow gully.
Gorey Harbour	At the western end of the Gorey north harbour wall, the contacts between the *Jersey Shale Formation* and Gorey granite – a variation of La Rocque granite – can be examined. The *Jersey Shale Formation* consists of dark grey, well-jointed siltstones and greywackes that were deposited in an Ediacaran (late Precambrian) deltaic environment. They underwent uplift, folding and erosion before being intruded by volcanic rocks in at least two stages. These dykes and veins have a range of sizes and contact relationships with the shale – some are planar along joint planes, while others show angular direction changes or small-scale faulting. Where the shale comes into contact with granite veins and dykes, there are signs of thermal metamorphism visible, such as hornfels and laminae in the greywacke. At the western end of the outcrop, there is a diorite exposure with white-yellow plagioclase feldspar crystals and black hornblende. It was intruded by undulating granite veins after it intruded the *Jersey Shale Formation*.

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