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Additional information:

Split into 3 parts: Report & Annex 1; Annex 2 Part A; and Annex 2 Part B

Authorised By	Monica Patterson
Designation	Depute Chief Executive
Date	30/08/16

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Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy	Regional	Good		X
Sedimentology	Local	Good		
Igneous/Mineral/ Metamorphic Geology	Local	Moderately good		
Structural Geology				
Palaeontology	Regional	Excellent		X
Geomorphology				

Site Geoscientific Value

Kilspindie Shore displays a cyclic sequence of sedimentary rocks belonging to the Carboniferous Lower Limestone Formation. The Hurlet Limestone, an important marker horizon for the base of the Lower Limestone Formation across the Midland Valley of Scotland, is exposed at this site. There are few natural exposures of the Lower Limestone Formation in central Scotland, making this a regionally important lithostratigraphic site.

Kilspindie Shore provides an excellent example of fossils with regional significance (in particular corals and brachiopods) preserved in good quality limestones. The site also provides a naturally exposed section through the Lower Limestone Formation which has regional litho-stratigraphical significance.

Assessment of Site: Current Site Value

Community	The site is visited daily by golf club users, although public access along the coast may be used less frequently.
Education	The site contains a wealth of fossils, in particular fossilised corals, which may have educational value for schools, higher education and research.

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion, sample/fossil collecting
Potential use	Research, Higher/Further Education, School Education.

Geodiversity Summary

The Kilspindie Shore section exposes a near continuous sequence from the top of the Strathclyde Group (Hurlet Limestone) up to the Blackhall Limestone, forming the lower part of the Lower Limestone Formation. Excellent exposures of the Hurlet Limestone allow the chance to examine fossils that lived during the Carboniferous at time of deposition, with the cyclic successions of siliciclastic rocks allowing interpretation of the subsiding deltaic environment and fluctuating sea level changes that deposited these rocks.

Site Photos

Photo ELC_14 P1: The Hurlet Limestone forms a striking rock platform along the shore at the eastern edge of the site. Thin beds of shale between limestones bed have been eroded out, leaving a stepped appearance to the limestone. Photo looking north-west. © BGS, NERC.

Photo ELC_14 P2: At the western edge of the site, a 20 cm thick coal seam is found beneath the Hurlet Limestone. In the photo the hammer is resting against a coal, with a brown shale layer above. The Hurlet Limestone caps this local sequence. © BGS, NERC.

Photo ELC_14 P3: Amongst the many fossils identifiable within the Hurlet Limestone are those of Koninckophyllum, a solitary coral. Crinoid fragments are visible surrounding the coral. Modern day barnacles (white) are commonly found on the limestone. © BGS, NERC.

Photo ELC_14 P4: This remarkable texture within the Hurlet Limestone is a dense concentration of the colonial coral fossil, Siphonodendron junceum. The fossils are so distinct that rocks bearing these fossils are locally given the name 'spaghetti-rock'. The bed is exposed just below high water mark, and large boulders or cobbles of the same rock type can be examined/collected at high tide. © BGS, NERC.

Photo ELC_14 P5: The Blackhall Limestone contains beautifully preserved crinoid stems, such as the ones imaged above. These crinoids lived in shallow waters, and would have been attached to the seat bottom by a stalk, the segmented remains of which are usually preserved in the fossil record. © BGS, NERC.

Photo ELC_14 P6: The Blackhall Limestone also contains beautifully preserved brachiopods, where the intricate details on their shells can still be seen today. © BGS, NERC.

Photo ELC_14 P7: Sandstone beds of the Lower Limestone Formation display weakly rippled surfaces, evidence of flowing water over the top of the sediment as it was deposited, possibly in a river bed or in a tidal environment. Modern day sand ripples reflecting in the sunshine can be seen on the right of photo. © BGS, NERC.

Photo ELC_14 P8: Analcime-gabbro of the Gosford Bay Sill is exposed adjacent to concrete tank deterrants at the far west of the site. Yellow lichen tends to prefer mafic rocks, giving the rock a false yellow colour. © BGS, NERC.

Photo ELC_14 P9: Erratics carried by glaciers are littered across the site. This example is a gabbroic erratic, displaying an excellent example of onion skin weathering, where orthogonal joint sets formed rectangular blocks are smoothed by weathering processes. © BGS, NERC.

Photo ELC_14 P10: The remains of a sea stack, King's Kist, can be seen in the middle of the site. © BGS, NERC.

ELC_15: Prestonpans Shore, Prestonpans

Site Information

Location and Summary Description:

The site comprises a 2.6km section of coastline at the town of Prestonpans. The site displays strata from the Upper Carboniferous, increasing in age from west to east. The important stratigraphic horizon of the Index Limestone, is seen at the site.

National Grid Reference: Mid-point: 338063,674308 South-west end: 336750,673838 North-east end: 338979,674900	**Site type**: • Natural section/exposure • Natural landform • Natural view
Site ownership: Crown Estates	Current use: Open shoreline
Field surveyors: Sarah Arkley and Eileen Callaghan	Current geological designations: None
Date visited: 30th April and 7th May, 2014	Other designations: Firth of Forth Ramsar, Wildlife site (Levenhall Links)

Site Map

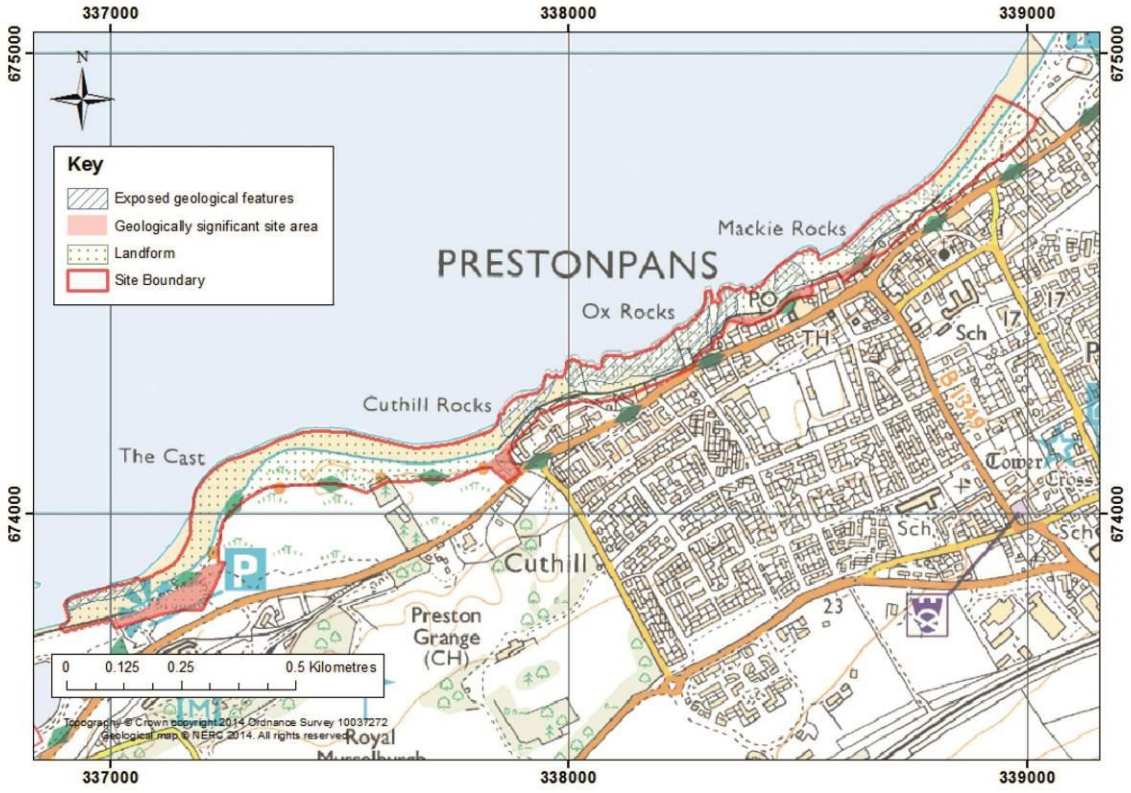


Figure 20: Prestonpans Shore Location Map. The site comprises areas of bedrock exposure (coastal rock platforms), and beaches. Bedrock exposure is likely to vary over time due to changes in beach morphology. Areas of the site important for access or viewing of features are included as geologically significant site areas

Site Description

Background

Prestonpans is located approximately 9 miles east of the City of Edinburgh. It is a town with a rich industrial heritage which has made use of its geological resources. Coal has been mined in this area for over a thousand years; originally it was used to boil seawater in large metal pans to produce salt. In more recent times the coal, clay and limestone deposits were used in the manufacture of bricks, pottery and glass.

Sedimentary Rocks

Carboniferous sedimentary rocks are exposed in rock platforms along the shore, with strata of the Limestone Coal Formation in the east of the site, overlain by the Upper Limestone Formation to the west.

The uppermost unit of the Upper Limestone Formation, exposed in the westernmost rock platform comprises a massive fine- to medium-grained, buff-coloured sandstone forming an intertidal shore platform (Photo ELC_15 P1). Sedimentary structures within the sandstones including ripples, cross-bedding (Photo_ELC_15 P2), and channels are indicative of deposition in fluvial environments. To the east the strata are cyclic, comprising beds of sandstone, mudstone and siltstones with ironstone beds and nodules (not greater than 5 cm). Fossilised worm casts are also present in the sandstone (Photo ELC_15 P3). The softer mudstones and siltstones are weathered leaving the sandstones more prominent. These cyclic strata were deposited at a time when sea-levels were rising and falling creating marine and deltaic environments.

The Index Limestone (Photo ELC_15 P4) is an important marker bed which divides the Upper Limestone Formation from the underlying Limestone Coal Formation. At this site the Index Limestone is pale to dark grey and although covered in barnacles, it is possible to identify fossil material: crinoidal debris, shells e.g. Productus sp. and gastropods (Photo ELC_15 P5). The limestone has a distinctive weathered appearance (Photo ELC_15 P6).

The Limestone Coal Formation is exposed in the eastern part of the site and comprises massive yellow sandstones with sandy mudstones to thinly bedded orange to buff coloured sandstones, grey mudstones, siltstones, sandy mudstone and ironstone nodules. The Limestone Coal Formation is typically characterised by the presence of thin coal seams, however coal outcrops are rarely seen within the site, possibly due to preferential erosion of the softer material. Organic rich mudstones and seatearths, commonly associated with coal, are seen in places on the rock platform (Photo ELC_15 P7). Sedimentary structures including ripples (Photo ELC_15 P8) and cross bedding are present in the sandstone and siltstone beds, indicating deposition occurred in a flat coastal deltaic environment. The prevalence of plant material in parts of the strata is also indicative of terrestrial settings.

Igneous Rocks

To the western edge of the site a black, ‘knobbly’, medium-coarse grained quartz-dolerite dyke is exposed at low tide. This rock belongs to the Central Scotland Late Carboniferous Tholeiitic Dyke Swarm and was intruded into the surrounding sedimentary rocks.

Structural Geology

Minor fractures within the sedimentary rocks are associated with alteration zones indicative of fluid flow (Photo ELC_15 P10). Mineralised veins associated with narrow zones of fault breccia (Photo ELC_15 P11) and offsets by minor fractures can be seen in the Limestone Coal Formation (Photo ELC_15 P12) indicating minor brittle deformation of the rocks.

Made Ground

The area known as Morrison’s Haven was previously an old harbour which was infilled in the 1960’s. A cliff section exposes spoil material approximately 3 metres high which includes sandstone boulders 30-40 cm in diameter, coal and ironstone nodules (Photo ELC_15 P9).

Access and Additional Information

Access to coastline at Prestonpans is tide dependant. The John Muir Way passes through Prestonpans. Access from the western car park is easy and the path can be followed offering views of the strata to the east. On entering the town the John Muir Way does not always follow the coastline but there are points where one can view the rocks. There are no interpretation panels along the John Muir Way within the town but near the car park at the western end of the site there are panels describing the old harbour ‘Morrisons Haven’. Interpretation panels within Prestonpans describe the Battle of Prestonpans in 1745 and there are several murals on the side of buildings highlighting the town’s

industrial heritage. The Prestongrange Museum is towards the south west of the site and exhibits Prestonpans industrial past.

Stratigraphy and Rock Types	
Age: Upper Carboniferous	Formation: Upper Limestone Formation
Rock type: Sandstone, siltstones, mudstones, limestones and a few coals	
Age: Upper Carboniferous	Formation: Limestone Coal Formation
Rock type: Sandstones, siltstones, mudstones, coals and ironstones	
Age: Carboniferous	Formation: Central Scotland Late Carboniferous Tholeiitic Dyke Swarm
Rock type: Quartz-microgabbro	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Good access from car parks located at Morrisons Haven to the west of the site and Preston Links to the east of the site. There is also parking within the town with access onto the shore.
Safety of access	Easy access to the shore but all visitors should be aware of the tide times when planning a visit, as most of the exposures are only visible at low tide. There is a walkway between the foreshore and the buildings but this can be very slippery and is also covered at high tide.
Safety of exposure	The rocky exposures have an uneven surface and are often slippery with seaweed. Stout footwear is recommended. The site is exposed to the open sea and the weather forecast should be checked before visits.
Access	Access is along the foreshore/beach and there are numerous footpaths leading down to the site from the town and car parks.
Current condition	The rocks can be covered in barnacles and seaweed. The exposures which are subsumed within local buildings are clean and free of vegetation.
Current conflicting activities	None known
Restricting conditions	Tide: many of the geological exposures are located in the intertidal range and therefore covered at high tide.
Nature of exposure	Intertidal and beach exposures.

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	Morrisons Haven is the locality of an old fort (pulled down by Cromwell in 1650) and harbour. In the 18th century the harbour was a busy port used to export salt, coal bricks and ceramics from Prestonpans. It was abandoned in the early 20th century and partly filled in. The Battle of Prestonpans, 1745 was fought just on the outskirts of Prestonpans. Historic houses within Prestonpans are Preston Tower (NTS dating from the 14th Century), Northfield House (17th Century) and Hamilton House (NTS, 17th Century).
Aesthetic landscape	Coastal
History of Earth Sciences	John Muir Way passes through Prestonpans
Economic geology	Prestongrange was an area of commerce and industry from the 13th Century. The coal mined in this area helped build the industries of glass

	making in 17th century, the first of its kind in Scotland. Salt panning in the 12th and 13th century, brick production and brewing (John Fowler & Co Ltd started brewing in 1720 in a former whisky distillery, brewing ceased in 1962 Coal mining ceased in 1961 and brick production ceased in 1975. Many of the buildings along the shoreline appear to have been built using local stone (Photo ELC_15 P13).

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy	Regional	Excellent		X
Sedimentology	Local	Good		
Igneous/Mineral/ Metamorphic Geology	Local	Moderately Good		
Structural Geology	Local	Good		
Palaeontology	Regional	Moderately Good		
Geomorphology				

Site Geoscientific Value

This site displays a sequence of coal bearing Upper Carboniferous strata from the Limestone Coal Formation to the Upper Limestone Formation. The Index Limestone is also exposed in a rare natural exposure of this important marker horizon within the Midland Valley of Scotland.

Prestonpans Shore provides an excellent example of Upper Carboniferous strata with regional lithostratigraphical and palaeontological significance.

Assessment of Site: Current site usage

Community	The easy access to the shore and the shore walkway is used regularly by locals. The John Muir Way passes through Prestonpans which attracts visitors from further afield.
Education	The site displays a variety of features suitable for amateur geologists to study depositional sedimentary environments. The exposure of the Index Limestone allows for the study of this important indicator as well as the fossils found within the strata.

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion; development of coastal defences
Potential use	On-site interpretation, on site geo-trail, school and higher education.

Geodiversity Summary

This site contains a good variety of geological features especially associated with sedimentary strata. It exposes a sequence of the Upper Carboniferous along with a dyke intruding into this sequence. The sedimentary structures seen allow interpretation of the terrestrial, deltaic and marine depositional environments of the upper Carboniferous.

The coastline is attractive and has easy access. There are numerous possibilities for adding geological interpretation to this site, especially along the John Muir Way.

Site Photos

Photo ELC_15 P1: Intertidal shore platform showing the barnacle covered massive bedded sandstone of the Upper Limestone Formation. This sandstone is medium grained, buff in colour and dipping to the south-east. Photo is looking to the south-west. © BGS, NERC.

Photo ELC_15 P2: An example of cross-bedding showing a curved base with the darker area of rock showing a sharp erosive top. This type of sedimentary structure can indicate the possible environemntal setting at the time the sands were deposited. In this case the sharp erosive top could indicate a deltaic palaeo environment. © BGS, NERC.

Photo ELC_15 P3: The features seen in the sandstone are known as trace fossils. These show animal activity during the time when the sediments were laid down. In this case the 'worm casts' show the trails and burrows made by most probably worms as they moved or burrowed through the sediment.. © BGS, NERC.

Photo ELC_15 P4: Index Limestone exposure (marks top of the Limestone Coal Formation). The limestone is approximately 60 cm thick, and would have been deposited in a warm shallow marine environment. Photo looking north north-west. © BGS, NERC.

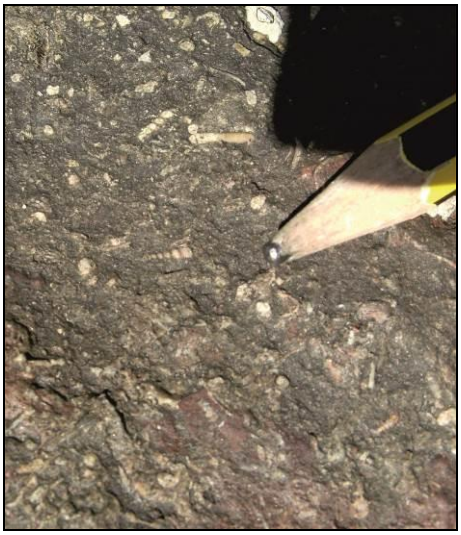


Photo ELC_15 P5: Shell debris including the spiral outline of a gastropod within the Index Limestone. Most gastropods are marine and live in shallow seas. © BGS, NERC

Photo ELC_15 P6: Erosive feature seen on surface of the Index Limestone. As limestone is soluble in water, joints in the limestone are easily weathered forming a feature known as a 'limestone pavement'; the slabs formed are known as 'clints' and the fissures are termed 'grikes'. © BGS, NERC.

Photo ELC_15 P7: Buildings at the foreshore incorporate outcrops of bedrock. In this case coal with ironstone nodules can be seen under the stone work. 'Seat earth' can be seen to the foreground of the photograph. Seat earth is a thin horizon of fossilized rootlets found beneath coals representing the soil in which the vegetation grew. © BGS, NERC

Photo ELC_15 P8: Ripple structures seen on the surface of the bedding plane. The ripples appear asymmetrical which indicates flow direction. In this case the more gently dipping side of the ripple (stoss side) appears to be to the left of the photograph whereas the steeper dipping side (lee side) appears to be to the right of the photograph. This indicates that the flow direction is from left to right. © BGS, NERC

Photo ELC_15 P9: A cliff section near Morrisons Haven showing the material used to infill the harbour, creating an area of made ground. The spoil used to form this made ground would probably have come from the old coal mine workings within the Prestonpans area. © BGS, NERC.

Photo ELC_15 P10: Fluid flow within fractures has redistributed iron throughout the sadnstone matrix, creating a handed 'halo' effect around fractures. © BGS, NERC.

Photo ELC_15 P11: A mineralised fault-breccia cross cuts mudstones and shale layers. The fault-breccia formed during faulting and related displacement of the strata, with fault-breccia clasts composed of the same lithology as the surrounding wall rock. © BGS, NERC.

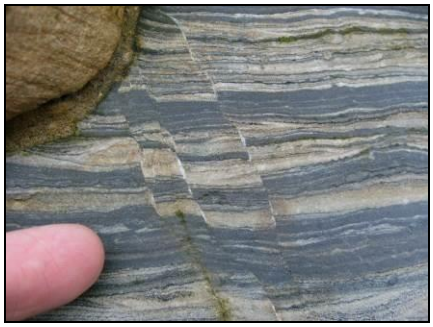


Photo ELC_15 P12: Faults with cm-scale, normal displacement are found throughout the site cross-cutting strata.. Some of the fault planes have been mineralised by calcite (white mineral), evidence that fault planes here acted as conduits to fluid flow. © BGS, NERC.

Photo ELC_15 P13: The buildings along the shoreline are composed mainly of local stone. Features such as cross-bedding and weathering processes can be seen in these building blocks. Here a plant fossil 'Lepidodendron' can be seen within the stone. © BGS, NERC.

ELC_16: Cockenzie and Port Seton

Site Information

Location and Summary Description:

Cockenzie and Port Seton are located approximately 9 kilometres east of Edinburgh. The 1.7 kilometre long site displays sedimentary strata from of the Carboniferous age Upper Limestone, Passage and Lower Coal Measures formations, which are locally intruded by dykes. The Crossgatehall Fault trends south-west to north-east through the site. This site is the only known natural exposure of the Lower Coal Measures Formation in East Lothian.

National Grid Reference: Mid-point: 340377, 675935 West end: 339611, 675632 East end: 341269, 675948	**Site type**: • Natural section/exposure • Natural landform
Site ownership: Crown Estates	Current use: Open shoreline
Field surveyors: Sarah Arkley and Eileen Callaghan	Current geological designations: Firth of Forth SSSI
Date visited: 14th May and 28th May 2014	Other designations: Firth of Forth SPA

Site Map

Figure 21: Cockenzie and Port Seton Location Map. The site comprises bedrock exposed in shore platforms and adjacent areas of beach. Bedrock exposures likely to vary over time due to changes in beach morphology. Areas of the site important for access or viewing of features are included as geologically significant site areas.

Site Description

Background

The villages of Cockenzie and Port Seton have a long and rich history; their harbours are used for fishing and in the past for the export of local coal. The coal that was mined within the area was used in the process of making salt and also to power the local power station. Cockenzie Power Station (ELC_16 P1) to the west of this site was opened in 1968 and was a major employer in the area but was decommissioned in 2013.

Sedimentary Rocks

The Lower Coal Measures Formation lies at the core of a gentle downward fold (syncline) within Port Seton Harbour. This formation is part of the Coal Measures Group and this exposure is the only one seen within East Lothian. The cyclic sequence shows mudstones, sandstones, siltstone and thin seams of coal which are exposed within the harbour at low tide (ELC_16 P2).

The older Passage Formation (exposed on either side and within the western wall of Port Seton Harbour due to folding) is part of the Clackmannan Group. The Passage Formation comprises a cyclic sequence of sandstone, mudstone, seatearths and siltstone with ironstone and limestone bands. The sedimentary rocks display typical sedimentary structures, including ripples and cross-bedding in sandstone, ironstone nodules within mudstones, and pebbly beds within sandstones, all indicative of formation in terrestrial fluvial environments. In places the sandstone is interbedded with thin mudstone and contains seat clays and palaeosols. Dessication cracks visible in the surfaces of some sandstone beds indicate periodic drying out of fluvial sediments during deposition. Fossilised trace fossils and marine shells are found within the sandstone, mudstone and limestone beds. Soft sediment deformation is also seen within the sandstone beds indicative of flows of sand during or soon after deposition. (ELC_16 P3).

Sedimentary rocks of the Upper Limestone Formation are exposed beneath the Passage Formation to the west and eastern margins of the site. The Upper Limestone Formation is composed of cyclic sequences of sandstones, siltstones, mudstones and thin limestones with seatearths, indicative of an alternating marine and deltaic environment (ELC_16 P4). The formation is exposed at Cockenzie Harbour where the strata comprise white to reddish, medium to coarse grained sandstone with cross and trough bedding (ELC_16 P5). Soft sediment deformation structures are well exposed and quartz pebbles are seen within the beds, possibly deposited quickly in a wet environment.

The Upper Limestone Formation exposed in the eastern part of the site comprises cyclic sequences of sandstone, which is occasionally pebbly, mudstone with ironstone nodules, siltstone, and prominent limestone with seatearths. Trace fossils and ripple structures are also seen in some exposures (ELC_16 6). The Calmy Limestone and the Orchard Limestone are exposed within the Upper Limestone sequence in the east of the site. The Calmy Limestone is exposed at low tide and is difficult to identify. It is approximately 40cm thick and is compact, fine-grained, grey/blue with crinoid debris (ELC_16 P7). The Orchard Beds are seen on the shore and towards the wall at West Links; the beds are separated by beds of sandstone, mudstone and siltstone. Two distinctive beds are seen; the lower bed is grey and contains numerous fossils including brachiopods, corals and crinoids (ELC_16 P8). The upper bed appears to contain more crinoid debris than the lower bed with fewer brachiopods and no corals seen.

Igneous Rocks

The Port Seton-Spittal Dyke is exposed in this site at Black Rocks to the west of Cockenzie Harbour, and also to the east at Cockenzie old harbour at Bell's Rocks (ELC_16 P9). The quartz dolerite dyke trends east west and is black in colour with a blocky appearance. Bands of coarser grained crystals can be seen within the rock indicating flow of the magma during dyke emplacement. The rock is fractured with mineralised veins and the larger of these fractures trend north-east to south-west. The dyke intruded into the surrounding sedimentary rocks and its contact with the Upper Limestone Formation can be best seen at Cockenzie old harbour. Here the quartz-dolerite is glassy in appearance, with numerous veins. The adjacent sandstone is hard and red with little structure which may indicate baking of the margin as the dyke was intruded (ELC_16 P10).

Quaternary Deposits and Landforms

The bedrock strata at the site are exposed on coastal rock platforms in the intertidal zone, which contains minor inlets and small bays. To the landward side of Cockenzie Harbour there is a section of a raised beach approximately 1 metre in thickness; this section contains closely packed shells (ELC_16 P11). East of Port Seton harbour there is a quartz dolerite erratic lying on the strata of the

Passage Formation.

Structural Geology

The site seen at Cockenzie and Port Seton is a broad syncline with axis running approximately south-east, north-west through Port Seton harbour. Younger strata of the Lower Coal Measures are exposed in the core of the syncline with older, underlying strata exposed on the eastern and western limbs. Minor faulting is observed in the Limestone Coal Formation (ELC_16 P12).

Access and Additional Information

Access to the coastal site is very good via the John Muir Way which follows the southern edge of the site boundary. The majority of the exposures only visible at low tide and the sedimentary strata tend to be partly covered with seaweed and barnacles. There is parking within Cockenzie and Port Seton and there are a few interpretation boards along the John Muir Way.

Stratigraphy and Rock Types

Age: Westphalian, Carboniferous	Formation: Lower Coal Measures Formation
Rock type: Sandstone, siltstone, mudstone with seatearths and coals	
Age: Namurian - Westphalian, Carboniferous	Formation: Passage Formation
Rock type: Sandstone, mudstone, siltstone and seatearths	
Age: Namurian, Carboniferous	Formation: Upper Limestone Formation
Rock type: Sandstone, siltstone, mudstone, limestone and seatearths.	
Age: Carboniferous	Formation: Central Scotland Late Carboniferous Tholeitic Dyke Swarm
Rock type: Quartz-Microgabbro	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	There is also parking within the town with access onto the shore.
Safety of access	Easy access to the shore but all visitors should be aware of the tide times when planning a visit, as the majority of the exposures are only visible at low tide and when exposed can be covered in seaweed.
Safety of exposure	The rocky exposures have an uneven surface and are often slippery with seaweed. Stout footwear is recommended. The site is exposed to the open sea and the weather forecast should be checked before visits.
Access	Access along the foreshore/beach, the John Muir Way follows the southern edge of the site.
Current condition	The rocks can be covered in barnacles and seaweed. The exposures at the landward edge of Cockenzie Harbour and at West Links are clear of vegetation.
Current conflicting activities	None
Restricting conditions	Tide: many of the geological exposures are located in the intertidal range and therefore covered at high tide.
Nature of exposure	Intertidal and beach exposures.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	The sea has played an important part in the history of both Cockenzie and Port Seton, Cockenzie has had a fishing harbour since the 16th century

	and the building of fishing vessels and yachts continued up to the 1990's. Both Cockenzie and Port Seton harbours were also used in the export of local coal and the locally mined coal was used in the extraction process of removing salt from seawater. Historic houses within or near Port Seton are: Seton Castle, privately owned, built on the site of 17th Century Seton Palace and also Seton Collegiate Church, 15th Century and managed by Historic Scotland.
Aesthetic landscape	Coastal
History of Earth Sciences	John Muir Way passes along the southern edge of the site.
Economic geology	Both Cockenzie and Port Seton harbours are still used in the fishing industry and local fish merchants and curers can be found in the town. Cockenzie Power Station was opened in 1968 and brought significant prosperity to the area but the power station was decommissioned in 2013. Tourism also adds to the towns in the form of Seton Sands Caravan Park which is located just outside Port Seton.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy	Regional	Excellent		X
Sedimentology	Local	Good		
Igneous/Mineral/ Metamorphic Geology	Local	Moderately Good		
Structural Geology	Regional	Good		
Palaeontology	Local	Good		
Geomorphology				

Site Geoscientific Value

This site displays a sequence of the Upper Carboniferous; the Upper Limestone Formation, the Passage Formation and the Lower Coal Measures Formation. Rare exposures of the Calmy and Orchard Beds Limestones are also found at this site.

Cockenzie and Port Seton provides an excellent example of Upper Carboniferous strata with regional lithostratigraphical and palaeontological significance.

Assessment of Site: Current site usage

Community	The easy access to the shore and the shore walkway is used regularly by locals. The John Muir Way passes through Cockenzie and Port Seton which attracts visitors from further afield.
Education	The site displays a variety of features suitable for amateur geologists to study depositional sedimentary environments. The limestone strata exposed in this site offers the study of fossils. The Port Seton-Spittal dyke is well exposed and provides some evidence of contact with the sedimentary rocks.

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion
Potential use	There are various places where on-site interpretation could be located also a geo-trail extending to Prestonpans could be considered. The area could be studied by, school and higher education.

Geodiversity Summary

This site contains a good variety of geological features especially associated with sedimentary strata. It exposes a sequence of the Upper Carboniferous including the Lower Coal Measures Formation, the only coastal exposure in East Lothian; also the Port Seton-Spittal dyke is seen intruding into this sequence. The sedimentary structures and the fossils seen in the Calmy and Orchard limestones allow interpretation of the depositional environments of each formation. The fossils at this site are one of the best exposures on the East Lothian coast.

The coastline is attractive and has easy access. There are numerous possibilities for adding geological interpretation to this site, especially along the John Muir Way.

Site Photos

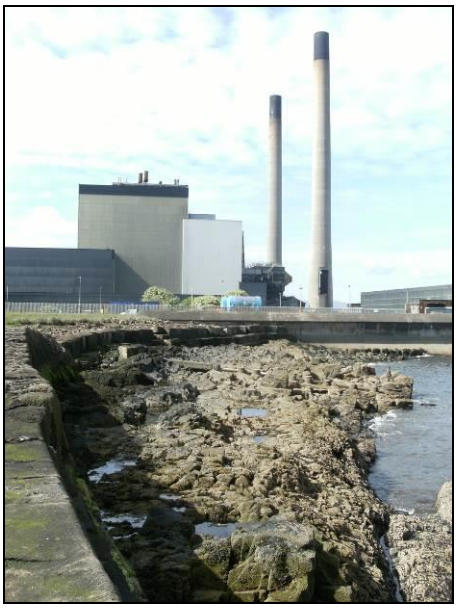


Photo ELC_16 P1: Cockenzie Power Station, looking west. The rocks in the foreground are the igneous rocks of the Port Seton-Spittal Dyke**.** © BGS, NERC.

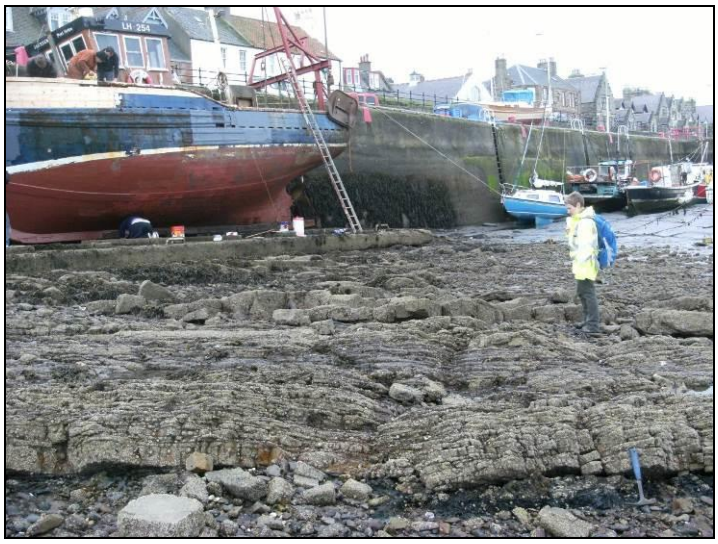


Photo ELC_16 P2: Port Seton Harbour; thinly bedded strata dipping south-west, of the Lower Coal Measures showing sandstones, mudstones and siltstones, a thin band of coal can be seen in the bottom right hand corner where the hammer is positioned. © BGS, NERC.

Photo ELC_16 P3: Soft sediment deformation within the Passage Formation, east of Port Seton harbour, looking south © BGS, NERC.

Photo ELC_16 P4: Upper Limestone Formation dipping towards the south-east exposed within Cockenzie Harbour, looking south © BGS, NERC.

Photo ELC_16 P5: Cross-bedded sandstone of the Upper Limestone Formation exposed near the slipway of Cockenzie Harbour. © BGS, NERC.

Photo ELC_16 P6: Rippled sandstone of the Upper Limestone Formation, with trace fossils seen. © BGS, NERC.

Photo ELC_16 P7: Calmy Limestone of the Upper Limestone Formation, pale grey/blue with crinoidal debris. © BGS, NERC.

Photo ELC_16 P8: Orchard Beds of the Upper Limestone Formation, a limestone rich in fossils including brachiopods and crinoid fragments. © BGS, NERC.

Photo ELC_16 P9: Quartz-dolerite dyke known as the Port Seton-Spittal Dyke creating a natural harbour wall at Cockenzie old harbour. © BGS, NERC

Photo ELC_16 P10: Contact between the quartz-dolerite dyke and the sandstone of the Upper Limestone Formation as seen at Cockenzie old harbour. The purplre/brown rock of the dyke can be seen in contact with the pale sandstone just above the handle of the hammer. © BGS, NERC

Photo ELC_16 P11: Shells in the raised bed section at Cockenzie Harbour near the slipway. © BGS, NERC.

Photo ELC_16 P12: Faulted strata within the Upper Limestone Formation, the limestone of the Orchard Beds on the right are faulted against the sandstone seen on the left. © BGS, NERC.

ELC_17: Esk Valley

Site Information

Location and Summary Description:

The site comprises a 1 kilometre stretch of gorge along the River Esk near the village of Smeaton. The section extends from Smeaton Bridge in the north to the confluence of the River North Esk and River South Esk, at the 'Meeting of the Waters' to the south. The site displays strata from the Middle Coal Measures Formation of the Upper Carboniferous.

National Grid Reference: Mid-point: 334206, 669403 South-west end: 333946, 669134 North-east end: 334481, 669663	**Site type:** • Natural section • Natural exposure
Site ownership: Smeaton Estate	Current use: Private estate
Field surveyors: Sarah Arkley and Eileen Callaghan	Current geological designations: None
Date visited: 7th May 2014	Other designations: River Esk Local Biodiversity Site, Smeaton Bridge is a Grade B Listed Structure

Site Maps

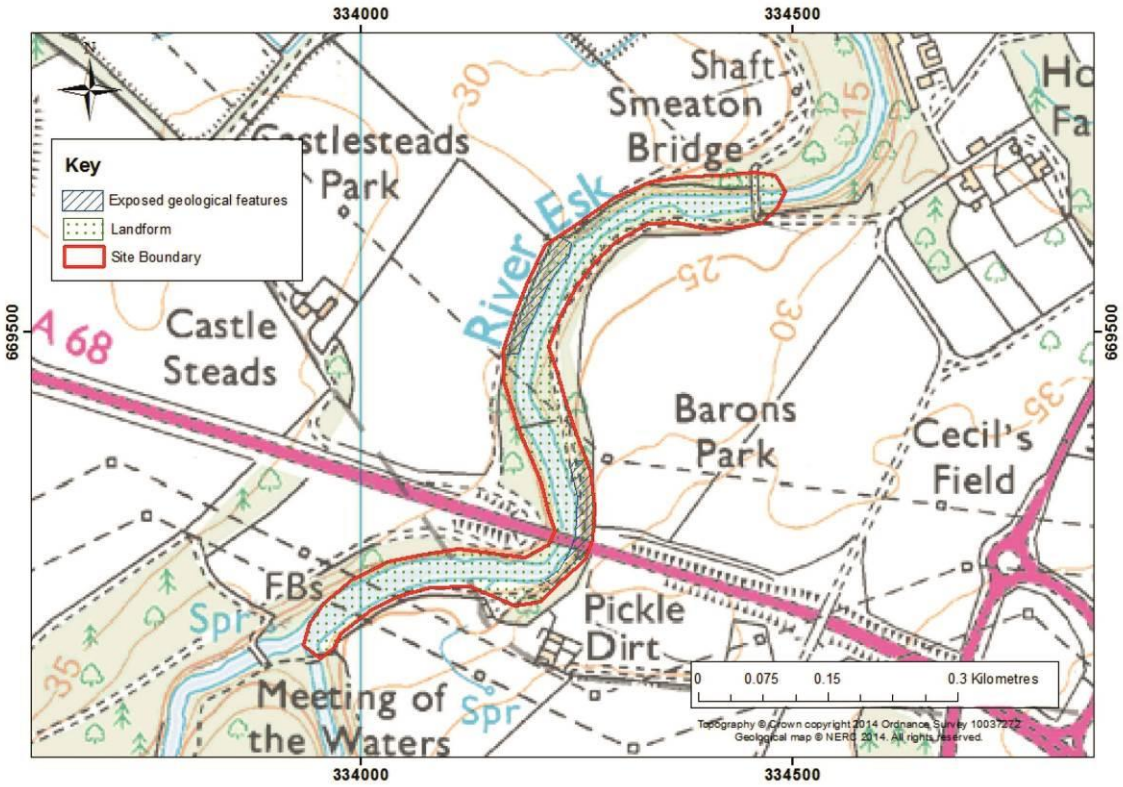


Figure 22: River Esk Location Map. The site comprises the incised gorge of the River Esk (landform) in which bedrock is exposed along the steep banks. The geologically significant area in the southern part of the site provides a good location for studying the cliff section.

Site Description

Background

Within East Lothian the River Esk flows from the council boundary just past the A68 and reaches the Firth of Forth at Musselburgh. This locality is the best exposure of the Middle Coal Measures Formation within East Lothian. The surrounding area has been mined for coal and Smeaton Colliery was located a few hundred metres to the south-west of this site in 1854. Also locally there was the Smeaton Brick and Tile Works which exploited the local clay, sand and coal deposits.

Sedimentary Rocks

The Middle Coal Measures Formation is a cyclic sequence of white, grey and brown sandstone and siltstone with dark grey mudstone and coals and seatearths. The sandstone and softer siltstone and mudstone are exposed in cliff sections along the west bank of the River Esk(ELC_17_P1). The sandstone is locally channelized (erosional base; ELC_17_P2), and the contact between the sandstone and underlying mudstone/siltstone is a sharp and erosive indicating high energy deposition in streams. In channel sandstones exposed on the east bank of the River Esk a layer of large carbonised wood and plant fragments can be seen at the base of the unit indicating that during flood flows, the channels carried woody debris and deposited it within the channel sediments (ELC_17_P5). Below the sandstone is a coal layer approximately 20cm thick (ELC_17_P6).

Access and Additional Information

Access to the River Esk at this locality can be made by parking within the village of Smeaton and crossing the A6094 at Smeaton Lodge. The road can then be followed down to Smeaton Bridge. Even though this is a private estate the area appears used by local dog walkers. A bridle path runs from Smeaton Bridge on the east side of the river to Pickle Dirt on the south side of the A68. The path is a pleasant walk giving access to exposures on the east bank of the River Esk and views to the exposures on the west bank of the River Esk. Two footbridges are marked on the 1:10 000 OS map but neither of these still cross the river, (ELC_17_P9), therefore not giving access to the west bank of the river or offering a circular route.

Stratigraphy and Rock Types

Age: Upper Carboniferous	Formation: Middle Coal Measures Formation
Rock type: Sandstone, siltstone, mudstone with seatearths and coals	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Parking can be found in Smeaton but as this is a very small village further parking can be found in Whitecraig. There is a pavement which follows the estate wall along the A6094 southwards towards Smeaton Lodge. The road easily leads down to Smeaton Bridge.
Safety of access	Care has to be taken when walking along the A6094, even though there is a good pavement. The bridle path along the River Esk may become slippy in wet weather so care should be taken, stout footwear is recommended. Care should also be taken when near the river particularly when it is in full spate.
Safety of exposure	The cliffs are continually eroding, so care should be taken at the base of the cliffs. When viewing the cliffs from the riverbank care should be taken to assess the flow of the River Esk.
Access	Access via tracks in open country.
Current condition	The rocks are well exposed, especially on the east bank of the river, some faces are covered in vegetation, especially the exposures on the west bank of the river.
Current conflicting activities	The site is on a private estate which may allow fishing although no signs or fishermen were seen.

Restricting conditions	The land is on a private estate which may restrict visiting although no signs suggesting this were noted.
Nature of exposure	River section exposing cliff sections along both banks.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	Smeaton Bridge is a single span sandstone bridge probably built of local stone.bridge and a Grade B listed building.
Aesthetic landscape	Pleasant tree lined walk along the River Esk.
History of Earth Sciences	Note applicable.
Economic geology	The Middle Coal Measures in East Lothian have been exploited for their deposits for the past two hundred years, located near to this location were Smeaton Colliery and Smeaton Brick and Tile Works.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy	Regional	Excellent		X
Sedimentology	Local	Good		
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology				

Site Geoscientific Value

This site displays the Middle Coal Measures Formation of the Upper Carboniferous. This is the best locality within East Lothian for seeing rocks of this age.

The River Esk provides an excellent example of the Middle Coal Measures Formation with regional lithostratigraphical significance.

Assessment of Site: Current site usage

Community	The site is easily accessible and is used at present by dog walkers and horse riders.
Education	The site displays a variety of features suitable for amateur geologists to study depositional sedimentary environments.

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion
Potential use	The bridle path along the River Esk could be developed as a short trail with on-site interpretation opposite a cliff section on the west bank and also the cliff section on the east bank exposing the coal. Footbridges across the river would enhance access and could connect the site to Dalkeith Country Park. The cliff sections are well exposed and would provide educational opportunities for the study of coal formation.

Geodiversity Summary

This site contains good exposures of largely fluvial sedimentary strata of the Middle Coal Measures Formation and is the best site to view these strata in East Lothian. The structures and different lithologies seen at this site help to understand the terrestrial depositional environments of the upper Carboniferous in the Midland Valley.

The walk along the River Esk is attractive, peaceful and easily accessed. There are possibilities for adding geological interpretation to this site.

Site Photos

Photo ELC_17 P1: Cliff section on the west bank of the River Esk. The buff coloured sandstone can be seen resting on the softer mudstone/siltstone which is undercuts the sandstone. © BGS, NERC.

Photo ELC_17 P2: The thinly bedded sandstone slightly obscured by vegetation appears to be a channel which has cut into the thicker bedded sandstone below. The sharp, erosive contact between the sandstone and the undercutting mudstone/siltstone can be clearly seen © BGS, NERC.

Photo ELC_17 P3: Interbedded sandston showing differing lithologies, the finer grained silty sandstone beds are being eroded more quickly giving rise to prominent beds of sandstone. © BGS, NERC.

Photo ELC_17 P4: Cliff section on the east bank of the River Esk. Exposure is showing massive bedded yellow/orange sandstone with a thin layer of coal exposed at its base. Erosive debris at the base of the section is obscuring the true thickness of the coal. © BGS, NERC.

Photo ELC_17 P5: Coal rafts seen in consolidated material at the base of the sandstone. The coal deposits may have been transported by the sand during deposition in a fluvial environment or are plants remains which have been carbonised into coal. © BGS, NERC.

Photo ELC_17 P6: 20cm layer of coal at the base of the sandstone. The coal is dull black, fractured and sulphurous, yellow staining can be seen. © BGS, NERC.

Photo ELC_17 P7: Cliff section continues along the east bank of the River Esk and has been used as a foundation for the A68 which crosses the river at this point. © BGS, NERC.

Photo ELC_17 P8: Cliff section exposing thick beds of sandstone interbedded with thinner beds of silty sandstone. Due to their lithology they are eroding more quickly than the thicker micaceous sandstone beds. The base of the thinner beds indicates a channel like structure. The coal exposed just north of this section is not seen at this location. © BGS, NERC.

Photo ELC_17 P9: The footbridge at the 'Meeting of the Waters' is no longer in use. © BGS, NERC.

ELC_18: Pencraig Wood Quarry

Site Information

Location and Summary Description:

The site comprises a disused quarry to the south-east of Pencraig Wood, approximately 2 km to the west of the village of East Linton. The quarry exposes a non-porphyritic intrusive trachyte sill. The car park and view point to the east and north of the quarry respectively have excellent views out across East Lothian.

National Grid Reference: Mid-point: 357286, 676536	**Site type**: • Artificial quarry works • Artificial section • Natural view
Site ownership: Viewpoint - East Lothian Council	Current use: Disused
Field surveyors: Rachael Ellen and Sarah Arkley	Current geological designations: None
Date visited: 16th April 2014	Other designations: None

Site Map

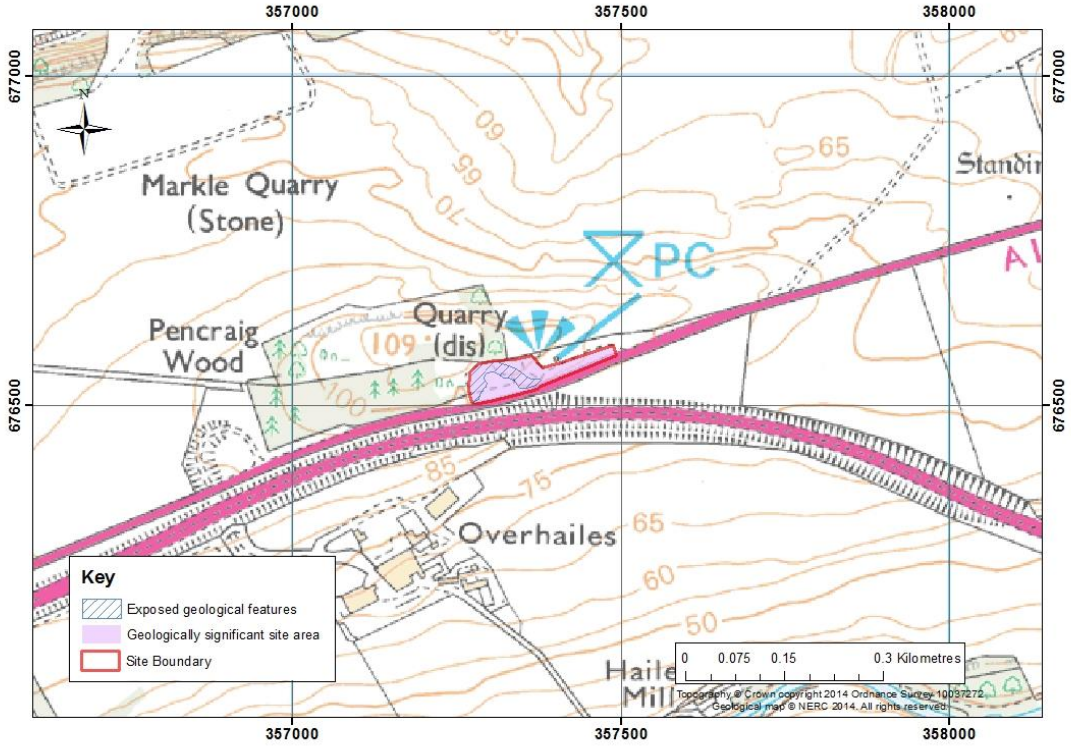


Figure 23: Pencraig Wood Location Map. Site boundary has been drawn to include rock exposures (blue hatched areas) and also site access and viewpoints (drawn as geologically significant site area).

Site Description

Background

The disused quarry within Pencraig Wood lies to the north of the A199. The woods in the high ground to the north of the quarry are used as an archery ground, but the quarry floor itself has no access restrictions. The quarry itself is easily accessed by foot from the lay-by to the east of the site, and there are footpaths in place toward the view point at the north of the site.

Volcanic Rocks

The massive, non-porphyritic fine-grained purple trachyte exposed at the site forms part of the Pencraig Sill, an intrusive igneous rock belonging to the Midland Valley Early Carboniferous Felsic Sill Suite (Photo ELC_18 P1). Sub-vertical fractures cut the trachyte throughout the extent of the exposure. Iron staining of the trachyte and small feldspar phenocrysts (5mm or less) are seen in fallen rock blocks on the quarry floor (Photo ELC_18 P2).

Geomorphology

There are excellent views towards North Berwick Law and Traprain Law from the lay-by east of the site (Photo ELC_18 P3), and the viewpoint just north of the car park (Photo ELC_18 P4).

Access and Additional Information

Access to the base of the quarry face is not recommended due to danger of rock fall. Gorse bush coverage also restricts access to part of the quarry face. Markle Quarry to the north of the site is currently being actively worked in the same lithology (Pencraig Sill).

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Midland Valley Early Carboniferous Felsic Sill Suite
Rock type: Trachyte	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Parking at the lay-by just to the east of the site is available. Walk along the pavement at the side of the road to access the old quarry.
Safety of access	Care should be taken walking along the pavement as the A199 is a busy and fast road. Car parking is available off the main road. The floor of the quarry is uneven and overgrown in places.
Safety of exposure	Recent rockfalls at the base of the cliff suggest the quarry walls are actively eroding, and potential loose material may fall. As with all quarry faces, care should be taken and an assessment made of each face before approaching.
Access	Access from main road.
Current condition	Gorse bushes and trees obscure most of the quarry walls, and there is a lot of rock debris at their base.
Current conflicting activities	None known
Restricting conditions	Access along the top of the quarry may be restricted due to the archery ground.
Nature of exposure	Vertical quarry faces

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological &	Not known

literary associations	
Aesthetic landscape	Good views out to the south of East Lothian, including the SSSI Traprain Law, from the viewpoint at the car park next to the site.
History of Earth Sciences	Not known
Economic geology	Quarry active since at least 1855 and abandoned between 1895 and 1908 (based on OS Historical Maps).

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology	Local	Poor		
Structural Geology				
Palaeontology				
Geomorphology	Local	Good		X

Site Geoscientific Value

The site exposes a fine-grained purple trachyte, which forms part of the Pencraig Sill. Whilst exposure of the rock is poor within the quarry, the car park adjacent to it provides spectacular views across the south of East Lothian, and the viewpoint provides views toward North Berwick Law. North Berwick and Traprain Law are impressive features on the landscape related to Carboniferous volcanic systems, and stand proud in the landscape due to glacial scouring of softer rocks surrounding these resistant volcanic rocks.

Pencraig Wood Quarry provides a poor example of an intrusive trachyte sill with local significance. It also provides a good viewpoint of local geomorphological features in the landscape which reflect East Lothian's volcanic past.

Assessment of Site: Current site usage

Community	The quarry is unlikely to be visited often; however the lay-by is often used and it is assumed the view point is accessed on a daily basis.
Education	At present the old quarry itself is unlikely to be used as an educational resource. Interpretation boards for the view at the lay-by and viewpoint are already in place, and these could be expanded on in order to explain the geology of the area.

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion, natural overgrowth.
Potential use	On-site interpretation

Geodiversity Summary

Pencraig Wood Quarry exposes a poor example of the Pencraig Wood trachyte sill. However, the lay-by adjacent to the quarry offers views across the south of East Lothian toward Traprain Law and pre-existing interpretation boards here could be expanded on to include more information about the local geology. An interpretation board at the viewpoint north of the quarry (providing views toward North Berwick Law) could also be expanded on to include details about the local geology.

Site Photos

Photo ELC_18 P1: Pencraig Wood Quarry. The quarry walls are overgrown by gorse and trees, and are covered at their base by rock fall. Photo looking toward the north. © BGS, NERC.

Photo ELC_18 P2: Iron staining of the trachyte within the quarry, caused by movement of fluids along pore space within the rock. © BGS, NERC.

Photo ELC_18 P3: View from the car park in the east of the site, looking southward toward Traprain Law. © BGS, NERC

Photo ELC_18 P4: View from the viewpoint to the north of the car park, looking northward toward North Berwick Law. © BGS, NERC.

ELC_19: North Berwick Law

Site Information

Location and Summary Description:

Located on the southern outskirts of North Berwick, North Berwick Law is a fine example of a crag and tail landform shaped by differential glacial erosion of a phonolitic trachyte plug. It forms a distinctive and characteristic landmark in East Lothian.

National Grid Reference: Mid-point: 355847, 684235 West end: 355295, 684150 East end: 356397, 684386	**Site type**: • Natural landform • Natural view • Artificial quarry works
Site ownership: Part council, part private	Current use: Open country, agricultural land
Field surveyors: Rachael Ellen, Eileen Callaghan, Sarah Arkley and John Gordon	Current geological designations: None (Formerly designated as a geological SSSI but denotified)
Date visited: 25th April, 20th Aug, 4th October 2014	Other designations: SSSI for Lowland calcareous grassland

Site Map

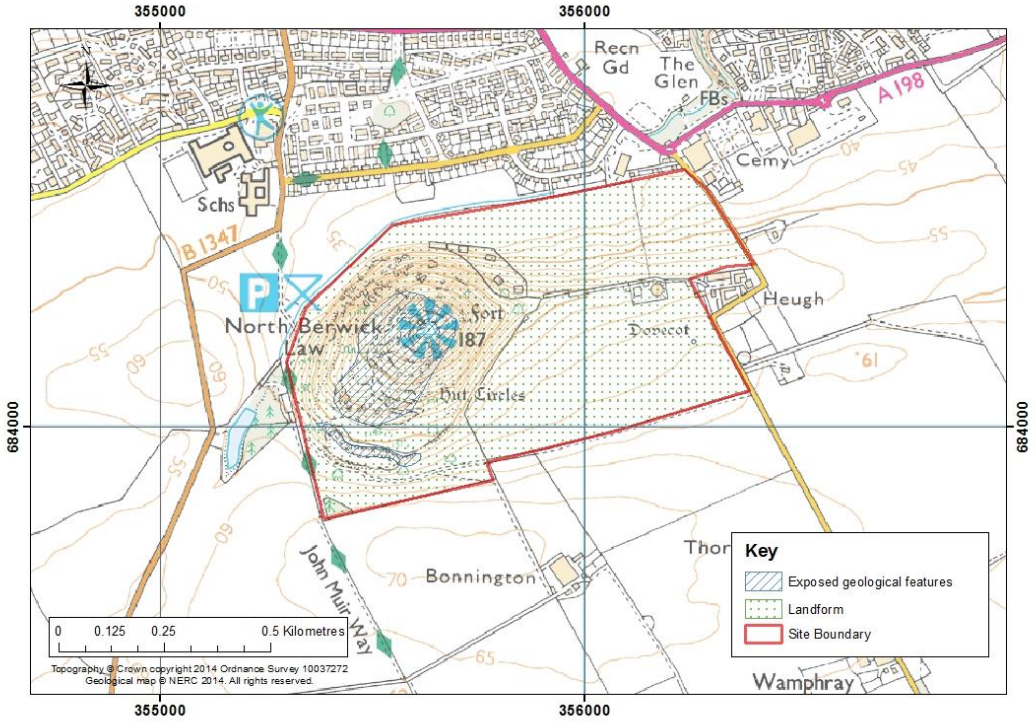


Figure 24: North Berwick Law Location Map. The site boundary includes the crag and tail feature of North Berwick Law and related bedrock exposures, only the proximal part of the landform 'tail' to the east is included. The site boundary coincides in part with that of the lowland calcareous grassland SSSI.

Site Description

Background

The site is a prominent landmark on the southern outskirts of North Berwick (ELC_19 P1) and widely visible from across the region and parts of Edinburgh and Fife. The summit of the Law provides an excellent viewpoint to appreciate the geology and landscape of East Lothian. Historically, the trachyte was quarried on the south side of North Berwick Law for building stones of many of the dwellings within North Berwick.

Igneous Rocks

North Berwick Law, the remnants of a Carboniferous volcanic plug, is composed of a medium-grained feldspathic phonolitic trachyte. The volcanic plug was probably exposed by weathering and erosion of the original volcanic structure over millions of years during pre-glacial times. The hard volcanic plug is more resistant than the adjacent Carboniferous basaltic lavas, tuffs and sedimentary rocks through which it was intruded. A disused quarry to the south of the site provides fresh exposures of the trachyte (ELC_19 P2), whilst there are plenty of weathered and glacially smoothed exposures to examine adjacent to the many paths leading to the summit of the Law.

Quaternary Deposits and Landforms

North Berwick Law rises some 120 m above the adjacent land surface. During the course of repeated Quaternary glaciations, it has been moulded by the passage of ice sheets from a westerly direction, forming a classic 'crag and tail' landform. Differential glacial erosion has enhanced the form of the 'crag', leaving a streamlined 'tail' of rock and glacial till over 1 km long on the more protected lee side to the east (ELC_19 P1, P3). Outcrops of ice-moulded rock occur on the upper slopes of the Law (ELC_19 P4). Overdeepened depressions are present to the north and south of the Law, due to the scouring of ice diverted around the base of the crag. This is most clearly seen on the south side; the northern depression being infilled by postglacial sediment. A glacial drainage channel occurs immediately to south west of the Law.

Access and Additional Information

The Law itself is easily accessible from North Berwick.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Southern Scotland Dinantian Plugs and Vents Suite
Rock type: Phonolitic trachyte	
Age: Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Basaltic tuff	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	North Berwick Law is probably best viewed from various locations in and around North Berwick. There is a free car park on the west side of the Law. North Berwick is accessible by train from Edinburgh and it is a short walk from the station to the Law. The town also has bus links with Dunbar, Haddington and Edinburgh. The John Muir Way passes along the west side of the Law.
Safety of access	Care is required if climbing to the summit of North Berwick Law due to the steep, rough path.
Safety of exposure	Care should be taken if visiting the quarry, the floor of which is becoming overgrown
Access	Access by footpath.
Current condition	Access to, and visibility of, the overall landform and quarry exposures are good. However, the floor of the quarry is becoming overgrown by vegetation.

Current conflicting activities	Rock climbing in the quarry may restrict access at times.
Restricting conditions	Rock climbing in the quarry may restrict access at times.
Nature of exposure	Disused artificial quarry works, hill with panoramic views and natural exposures.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	An Iron Age hill fort and hut circles are present on the Law. There are also the remains of buildings that were used as lookouts in the Napoleonic Wars and the Second World War. North Berwick Law also formed a backdrop to sketches by JMW Turner of Tantallon Castle (see < http://www.tate.org.uk/art/artworks/turner-tantallon-castle-and-north-berwick-law-d13332>).
Aesthetic landscape	Coastal landscape; hill
History of Earth Sciences	The John Muir Way passes through the site.
Economic geology	Red phonolite was extracted from the former quarry on the south-west side of the Law to build many of the distinctive historic buildings of North Berwick.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology	Regional	Good		
Structural Geology				
Palaeontology				
Geomorphology	Regional	Good		X

Site Geoscientific Value

North Berwick Law is an Good example of a crag and tail landform associated with resistant volcanic outcrops in lowland glaciated terrain. The phonolitic trachyte rock of the Law is rare in the Midland Valley of Scotland.

North Berwick Law is regionally significant for both its bedrock and geomorphological aspects. It is a particularly good example of a distinctive glacial landform that occurs commonly in the Midland Valley, and a good example of a phonolite volcanic plug.

Assessment of Site: Current site usage

Community	The Law is a popular local walk. It is managed as a Countryside Site by East Lothian Council.
Education	The site is a good educational example of a crag and tail landform, and of a volcanic plug.

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering/erosion, natural overgrowth, likelihood of development.
Potential use	School education, on-site interpretation linking geology and archaeology interests, link to coastal geological walks and the John Muir Way. The site could also be incorporated into existing interpretation materials, such as those provided by the Scottish Earth Science Education Forum and Lothian and Borders RIGS Group.

Geodiversity Summary

North Berwick Law is a good example of a Carboniferous volcanic plug, and an excellent example of a crag and tail landform indicative of the lowland glaciation of East Lothian. The site is easily accessible and there is good potential for improving the interpretation and educational use of the site.

Site Photos

Photo ELC_19 P1: North Berwick Law crag and tail viewed from the south-east. © John Gordon.

Photo ELC_19 P2: Former quarry on the south-west side of North Berwick Law showing exposures of phonolitic trachyte. The quarry floor and faces are becoming overgrown in places. © John Gordon.

Photo ELC_19 P3: North Berwick Law crag and tail: view looking down on the 'tail' from near the summit of the Law. © John Gordon.

Photo ELC_x19P4: Ice-moulded bedrock near the summit of North Berwick Law © John Gordon.

ELC_20: Kidlaw Quarry

Site Information

Location and Summary Description:

The site comprises a disused quarry just to the north-west of Kidlaw Farm, 5 km south-west of Gifford. The site exposes basanite, an extrusive basaltic rock composed chiefly of plagioclase, olivine and augite. The Kidlaw Plug belongs to the Scottish Carboniferous to Early Permian Plugs and Vents Suite.

National Grid Reference: Mid-point: 350689, 664322	**Site type**: • Artificial quarry works
Site ownership: Kidlaw Farm	Current use: Disused quarry adjacent to pastoral land.
Field surveyors: Rachael Ellen and Eileen Callaghan	Current geological designations: None
Date visited: 10th June 2014	Other designations: None

Site Map

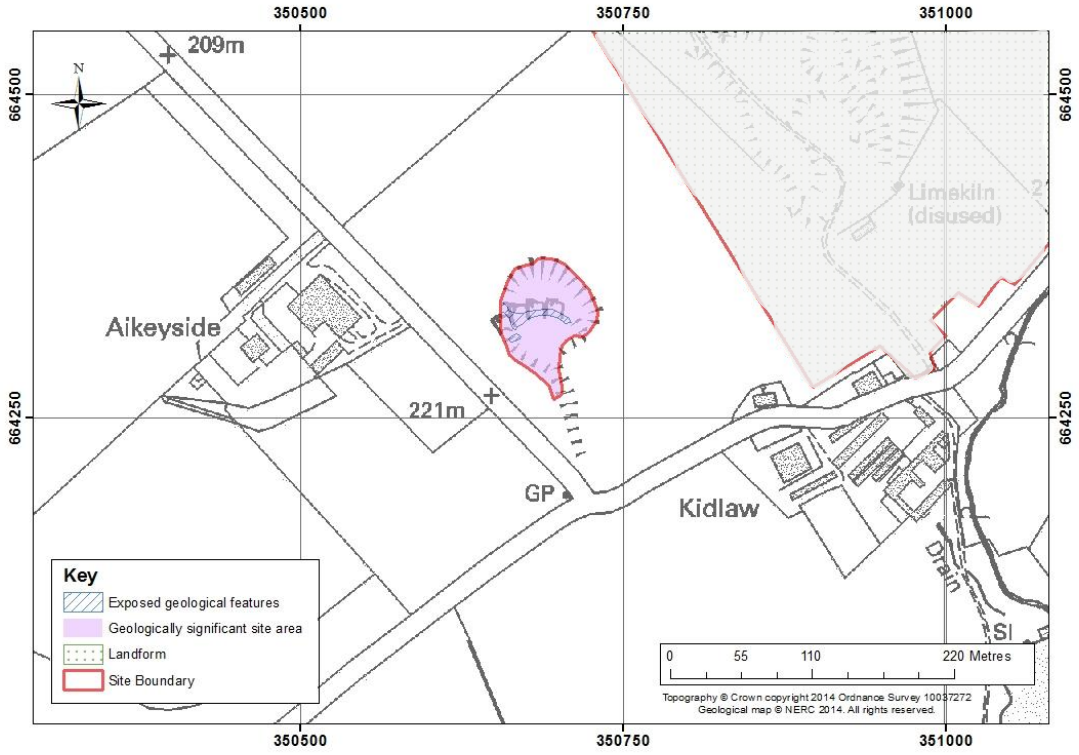


Figure 25: Kidlaw Quarry Location Map. The site boundary has been drawn to include the rock exposures within the quarry, and related access and viewpoints (geologically significant site areas). The site boundary for the Kidlaw Erratic (ELC_22) to the east is included for reference (shaded area).

Site Description

Background

The quarry was opened between 1855 and 1895, and was worked until at least the 1920's for road-metal; it was once regarded as one of the better sources of road-metal in East Lothian (Ewing, 1913). The analcime-basanite exposed in the quarry was originally thought to be a sill intruding into the country rock by Clough et. al. in 1910. However, a fresh phase of quarrying in the 1920's exposed a vertical contact between tuff and basanite leading Simpson (1928) to suggest that it was in fact a volcanic plug.

Today the quarry is accessed via a muddy grass path from a gate at the junction of two roads to the west of Kidlaw Farm (ELC_20 P1). The quarry floor is overgrown by vegetation, and is uneven due to agricultural and other rubbish dumped in the pit (ELC_20 P2). The south-eastern face of the quarry is completely covered by a rubbish tip.

Volcanic Rocks

The main quarry face to the north is approximately 5 metres high, composed of a dark grey, fine-grained basanite (a silica poor, alkali rich form of basalt, associated with continental rift magmatism) displaying roughly columnar cooling joints (ELC_20 P3). The basanite is occasionally porphyritic, containing phenocrysts of olivine, augite (ELC_20 P4) and plagioclase. The groundmass contains alkali feldspars with analcime, which have been weathered out and account for the speckled nature of some of the weathered surfaces in the quarry (ELC_20 P5). The basanite also contains ultra-basic nodules (0.5 – 2 cm in diameter), which are interpreted as altered spinel lherzolites. The ultra-basic rocks are rich in elements such as magnesium and iron, which have been altered through hydrothermal processes (ELC_20 P6). The basanite also contains clasts of biotite granites, which are believed to be related to a Devonian age granite intrusion 500 m to the ESE of the quarry (ELC_20 P7). Agates are known to have been collected from the quarry in the past. A number of the joints running throughout the basanite are mineralized, some displaying excellent examples of quartz prisms (ELC_20 P8).

A fissile, grey – brown tuff and breccia dyke is intruded in the basanite to the west of the quarry. The dyke, and basanite adjacent to the dyke, is well jointed and mineralized. The mineral veins form impressive cross-cutting relationships (ELC_20 P9), and multiple phases of mineralisation (clay and carbonate minerals) can be identified (ELC_20 P10).

N.B. The East Lothian Guide Book mentions that small outcrops of reddish tuff can be seen upon entering the quarry – however, at time of visit, the tuff is no longer visible due to the area being overgrown and covered by tipped waste.

Access and Additional Information

Access to the site is by a gate at the junction of two minor roads to the west of Kidlaw Farm [350710 664203]. Parking is possible at Kidlaw Farm with permission from the farmer. The quarry is accessed track which leads to the quarry. The quarry face is accessible and relatively stable but due care should be taken when working beneath quarry faces. The ground of the quarry is uneven due to teh presence of tipped waste.

N.B. The Kidlaw Erratic (ELC_22) lies 170 m to the east of this site.

Stratigraphy and Rock Types

Age:Carboniferous	Formation: Kidlaw Plug - Scottish Late Carboniferous to early Permian Plugs and Vent Suite
Rock type: Basanite	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Good access and parking for the quarry with the farmer's permission.
Safety of access	Rough uneven ground within the quarry. Caution if cattle are in the field.
Safety of exposure	Care should be taken as in all quarries, and an assessment made of each

	face before approaching. The quarry faces are relatively stable.
Access	Access via farm tracks and agricultural land.
Current condition	Good exposure of basanite and tuff within the quarry but no exposure of the reddish tuff mentioned in previous documentation due to the ground being overgrown.
Current conflicting activities	Farming
Restricting conditions	Cattle
Nature of exposure	Outcrop and quarry faces.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	Quarried up to at least 1926 for road-metal. Considered one of the best quarries for road-metal in East Lothian.
Aesthetic landscape	No association
History of Earth Sciences	Revised interpretation of a sill (1910) to a plug in a vent (1928)
Economic geology	Quarried up to at least 1926 for road-metal. Considered one of the best quarries for road-metal in East Lothian.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology	Regional/ National	Good	Simpson (1928), Clough et al., (1910) Ewing (1913)	X
Structural Geology				
Palaeontology				
Geomorphology				

Site Geoscientific Value

The site comprises a good exposure of analcime-basanite, forming a plug within a volcanic vent, which allows interpretation of the volcanic character of East Lothian during the Late Carboniferous to Early Permian. Xenoliths of granite and ultra-basic nodules allow interpretation of the strata the basanite was intruded into. Numerous plugs of volcanic material are littered throughout the Midland Valley, but very few are composed of analcime-basanite.

Kidlaw Quarry provides a good example of an analcime-basanite plug with regional to national significance.

Assessment of Site: Current site usage

Community	The quarry is in open countryside, and rarely used by the local community. There is little aesthetic value for the community to visit the site due to rubbish within the

	quarry, and the use of the field for sheep and cattle grazing.
Education	The site presents the best, albeit artificial, exposure of an analcime-basanite plug in East Lothian. This site may be a **good locality for educational fieldwork** relating to basanite petrology and xenolith studies within Carboniferous intrusions in Scotland.

Assessment of Site: Fragility and potential use of the site	
Fragility	Natural overgrowth, geohazard
Potential use	School education, higher/further education

Geodiversity Summary

The analcime-basanite exposure within Kidlaw Quarry provides a good opportunity to study textures and mineralogy of a Carboniferous volcanic plug. It allows an interpretation of the country rocks the plug intruded into, and an appreciation of the scale and diversity of volcanic activity throughout East Lothian.

Site Photos

Photo ELC_20 P1: Entrance to Kidlaw Quarry is accessed via a muddy grassy track through grazing fields. Photo looking north. © BGS, NERC.

Photo ELC_20 P2: Kidlaw Quarry. Basanite outcrops to the right of the photo, with the tuff and breccia dyke cropping out in the centre of the photo on the grass bank. The quarry is littered with recent rubbish including tyres, bits of concrete, bits of machinery etc. Photo looking west. © BGS, NERC.

Photo ELC_20 P3: The north face of Kidlaw Quarry is composed of basanite, a mafic igneous rock. The basanite displays sub-vertical cooling joints, with a roughly columnar form. Photo looking north, © BGS, NERC.

Photo ELC_20 P4: Augite phenocryst within basanite. © BGS, NERC

Photo ELC_20 P5: The speckled appearance of some of the weathered surfaces within the basanite is due to weathering of alkali feldspar with analcime. These weathered out crystals are around 2mm in diameter. © BGS, NERC.

Photo ELC_20 P6: Ultrabasic nodules are found within the basanite. On weathered surfaces, these nodules are replaced by soft clay, and as a result weather in to form shallow hollows. © BGS, NERC.

Photo ELC_20 P7: Xenoliths of biotite granite are found within the basanite, and are thought to be related to a Devonian granite 500 m to the ESE of the quarry. © BGS, NERC.

Photo ELC_20 P8: Cooling joints within the basanite are occasionally mineralized. The example above has been mineralized by quartz. The quartz has formed prisms (see above finger) - this crystal morphology gives a clue as to the mineralization history of this joint. For quartz prisms to form, the quartz must be growing into, and finish forming, in an empty space, otherwise, a solid vein would form. This suggests this particular cooling joint was open when the quartz formed, allowing the beautiful natural crystal shape of quartz to form. © BGS, NERC.

Photo ELC_20 P9: Joints within the basanite (adjacent to the intruded tuff and breccia dyke) are mineralised, and form impressive cross-cutting relationships. The mineral veins are typically sub vertical, and stand proud of the surrounding rock. © BGS, NERC.

Photo ELC_20 P10: Unlike the quartz mineralisation of the basanite in the north face of the quarry, in this western sector of the quarry, orange clay and white carbonate minerals fill the joints. In the photo, the margins of the vein (white) represent carbonate minerals, and the orange/brown centre represent clay infill. This suggests this vein saw at least two fluid phases – one which precipitated firstly the vein marginal carbonate, followed by fluid which precipitated clay in the remaining joint space between the carbonate mineral linings. © BGS, NERC.

ELC_21: Cheese Bay

Site Information

Location and Summary Description:

Cheese Bay is a small, 70 m wide bay, situated 2.5 km to the north-west of Dirleton. The site is well known within the geological community for its palaeontological links. Historically, a wealth of fossilised shrimp, fish and other fossils from the Carboniferous were found in situ here. Today there is little left of the fossiliferous bed *in situ*, due to erosion and vandalism, but fossiliferous pebbles can be found on the adjacent beach**.**

National Grid Reference: Mid-point: 349242, 685684	**Site type**: • Natural section/exposure • Natural landform
Site ownership: unknown	Current use: Open country
Field surveyors: The site was not surveyed in the field. Information was derived from desk study.	Current geological designations: Cheese Bay GCR (GCR ID: 2916); part of Firth of Forth SSSI
Date visited: N/A	Other designations: Firth of Forth SPA and Ramsar.

Site Map

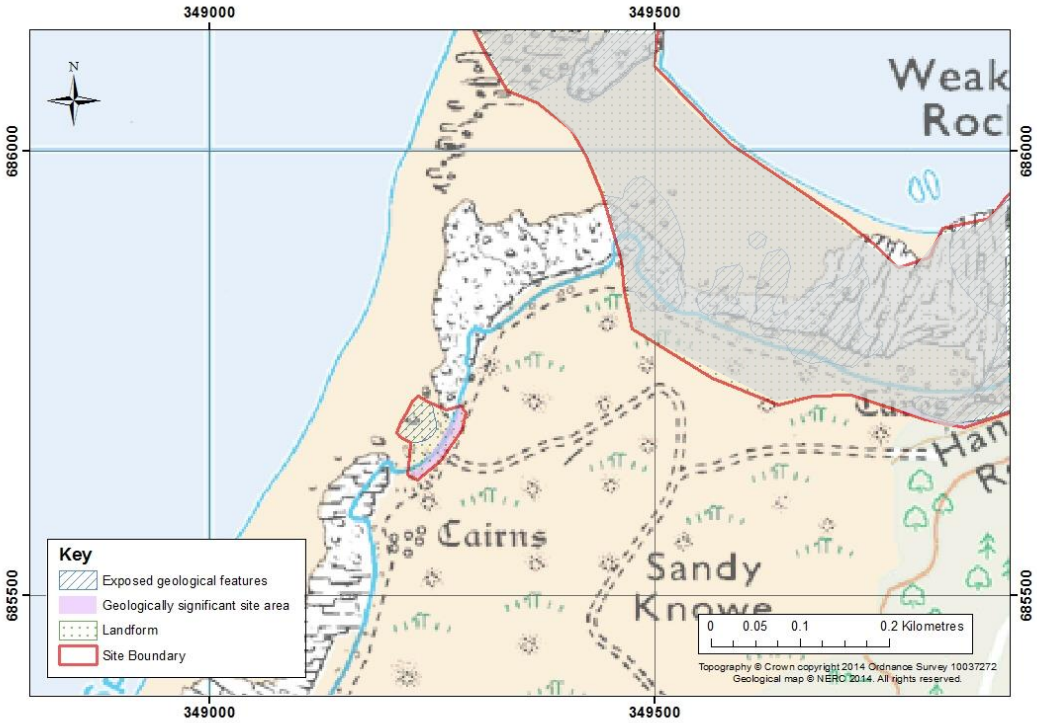


Figure 26: Cheese Bay Location Map. The site boundary has been drawn to include the bedrock exposure containing the Shrimp Bed for which Cheese Bay is known. The adjacent intertidal zone and is also included due to its potential for containing fossiliferous mudstone pebbles, derived from the Shrimp Bed. The adjacent Yellowcraigs ELC site (ELC_6) is shown for reference (shaded grey area).

Site Description

Background

Cheese Bay, so called due to a ship laden with cheese which was historically wrecked nearby, is a small bay 1 km to the west of Archerfield Golf Course. This site is a GCR site due to its palaeontological importance, as it is the type locality for *Rhadinichthys formosus* (Traquair, 1904), a Lower Carboniferous fish.

Sedimentary Rocks

The rocks at Cheese Bay belong to the Gullane Formation, and comprise a sequence of cementstones, dolomites, mudstones and black shales. The rocks have been deformed and altered by an intrusive dolerite sill nearby. The black shale layers in particular yield a rich and diverse assemblage of Lower Carboniferous marine fossils, including ostracods, fish scales, pyritised plants, fish fauna, shrimp fauna (such as *Tealliocaris woodwardi,* see ELC_21 P1) and one recorded find of the tetrapod *Casineria kiddi* (Paton et al., 1999). Up until recently, this tetrapod represented the earliest terrestrial vertebrate discovered during the Carboniferous (see ELC_3, Gin Head). Dineley & Metcalf (1999) recorded 10 genera of fossilised fish at this site. A list of fossils recorded at this site can be found within the GCR Document (GCR ID: 2916). An interpretation of this site provided by Briggs and Clarkson (1983) suggested that during the Lower Carboniferous, the rocks of Cheese Bay were originally formed in an environment dominated by tidal flats in nearshore intertidal conditions with dried-out pools.

Access and Additional Information

The fossil bearing beds are only occasionally exposed at low tide, but pebbles from the adjacent beach are known to contain fossils from the site. Removal of fossil finds is discouraged. The in-situ fossil beds are fragile due to erosion, and have already been subject to destruction and vandalism due to fossil collection.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Gullane Formation, Strathclyde Group
Rock type: Dolomite, sandstone, siltstone and mudstone	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Public access is best achieved by parking in the Yellowcraig Plantation car park to the east, and walking westward along the coastal path to get to Cheese Bay. It may be possible (with permission) to access the site via Archerfield Golf Course.
Safety of access	The walk to the site is just under 3 km from the Yellowcraig Plantation, mostly along a coastal path. However, the site itself is only exposed at low tide, and therefore all visitors should be aware of the tide times when planning a visit.
Safety of exposure	Stout footwear is recommended for coastal path and the weather forecast should be checked before visits.
Access	Access along the foreshore/beach and dune area.
Current condition	The rocks can be covered in barnacles and seaweed, and erosion/vandalism has removed a lot of the exposure.
Current conflicting activities	None known
Restricting conditions	The site is only accessible at low tide
Nature of exposure	Intertidal exposure

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	Cheese Bay is the site of a ship wreck reputed to have been carrying cheese.
Aesthetic landscape	Coastal
History of Earth Sciences	Type locality of fish fossil *Rhadinichthys formosus* (Traquair, 1904)
Economic geology	No known association

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy	Local	Moderately good		
Sedimentology	Local	Moderately good		
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology	International	Excellent	Traquair, 1904, 1907; Clough et al., 1910; Briggs and Clarkson 1983; Dineley & Metcalf, 1999; Paton et al., 1999.	X
Geomorphology				

Site Geoscientific Value

The exceptional range of fossils, in particular shrimps, fish and tetrapod, found historically within this site merits a designation of 'international' in rarity. The site is also the type locality for *Rhadinichthys formosus* (Traquair, 1904). However, the site is only occasionally exposed at low tide, and the site has suffered vandalism in the past, rendering actual in-situ localities of fossils extremely rare. There are however pebbles of shale on the beach which are known to contain fossils from this nearby outcrop.

Cheese Bay is of international importance due to its exceptional and diverse range of fossils from the Lower Carboniferous.

Assessment of Site: Current site usage	
Community	Rarely visited, although passed regularly by golfers and coastal path walkers.
Education	The site has significant importance in understanding the diverse fauna that existed during the Lower Carboniferous. The site is therefore an excellent locality for educational fieldwork and research. The geodiversity of the site could be further promoted by a geo trail linking this site with the nearby Yellowcraigs site (ELC_6).

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering/erosion, fossil collecting
Potential use	On site geo-trail, school and higher education, research.

Geodiversity Summary

Cheese Bay preserves a wealth of fossils, ranging from ostracods and shrimps, to fish and tetrapods and as such is extremely important in understanding Lower Carboniferous environments and how fauna existed within those environments. The site is already designated as a GCR, but is an at risk site due to fossil collection and coastal erosion.

Site Photos

Photo ELC_21 P1: *Tealliocaris woodwardi* is a crustacean that lived during the Carboniferous. This specimen was collected at Cheese Bay, and lived during a period of fluvio-deltaic conditions with short-lived marine incursions. This fossilised shrimp has three sections: a head with eye on stalks and antennae, a thorax, and an abdomen. © BGS, NERC.

ELC_22: Garleton Hills

Site Information

Location and Summary Description:
The Garleton Hills form a distinctive area of ice-moulded volcanic hills located 2.5 km north of Haddington.

National Grid Reference: Mid-point: 351017, 676294	**Site type**: • Natural landform • Natural view
Site ownership: not known.	Current use: Agricultural land (mainly)
Field surveyor: John Gordon	Current geological designations: SSSI (Igneous petrology: Carboniferous - Permian Igneous); GCR ID 1155
Date visited: 26th September 2014	Other designations: None known

Site Map

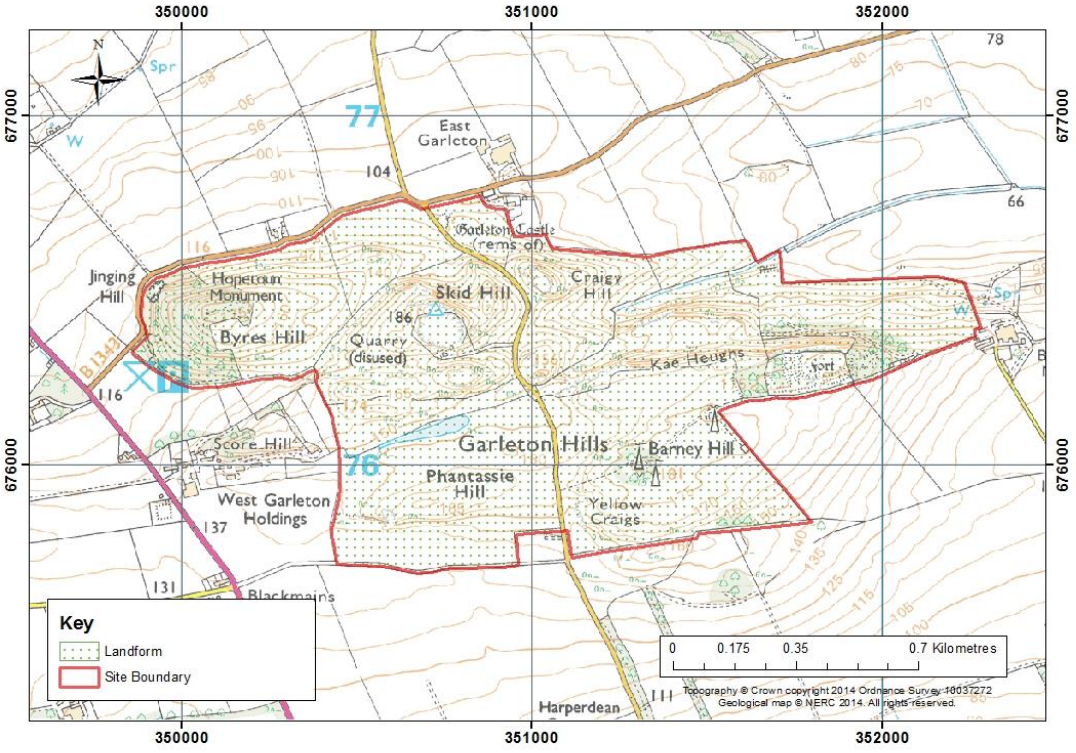


Figure 27: Garleton Hills Location Map. The site boundary covers an area of erosional glacial landforms. The area contains numerous exposures of volcanic bedrock, but these have not been marked as they are already covered by SSSI designation.

Site Description

Background

The Garleton Hills form a prominent area of higher ground to the north of Haddington that has been streamlined and moulded by glacial erosion. The site boundary includes the core area of glacial landforms, and largely coincides with the boundaries of the SSSI.

Quaternary Deposits and Landforms

The Garleton Hills form an area of low hills, comprising the more resistant remnants of an area of trachyte and basaltic lavas, belonging to the Garleton Hills Volcanic Formation of Carboniferous age.

The hills have the form of an escarpment, the lavas dipping southwards (ELC_22 P1) with a series of rock ridges and scarps facing north (ELC_22 P2). The lavas are more areally extensive than the present area of higher ground, suggesting scarp retreat from the north by erosion during pre-glacial times and latterly by ice sheets during the course of repeated Quaternary glaciations. Glacial erosion has streamlined the hills in a direction slightly north of east, in alignment with other indicators of ice movement in the area, producing a smooth, ice-moulded outline when viewed from the south (ELC_22 P1). At a more detailed level, differential glacial erosion of the scarps has formed several fine examples of crag and tail landforms, with steeper slopes facing westwards and streamlined tails extending eastwards (e.g. Byres Hill and Craigy Hill, ELC_22 P3, P4). Skid Hill also has the form of a roche moutonnée when viewed from the north. Several deep channels run between the scarps. These were probably formed by glacial erosion but also occupied by glacial meltwaters (ELC_22 P2). Clough et al. (1910) described a series of ice-marginal meltwater benches along the northern slopes.

The Hopetoun Monument on Byres hill provides an excellent viewpoint to appreciate the geology and landscape of East Lothian.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Trachyte, plagioclase-macrophyric basalt	
Age: Carboniferous	Formation: Southern Scotland Dinantian Plugs and Vents Suite
Rock type: Tuff and breccia	
Age: Carboniferous	Formation: Central Scotland Late Carboniferous Tholeiitic Dyke Swarm
Rock type: Quartz-microgabbro	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	There is good access from Haddington via the A6137 and B1343 with parking near Hopetoun Monument, an East Lothian Council Countryside Site. A minor road with limited roadside parking runs across the hills between Haddington and Drem.
Safety of access	There is a footpath to the summit of Hopetoun Hill and other footpaths and tracks allow the main landforms to be viewed.
Safety of exposure	Not applicable
Access	Access possible by footpaths, the site can also be viewed from roads.
Current condition	Generally good, the area is largely agricultural land.
Current conflicting activities	None known
Restricting conditions	None known
Nature of exposure	Landscape feature, glacial landforms.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	There is a prehistoric fort at Kae Heughs, near Barney Mains.
Aesthetic landscape	The Garleton Hills provide excellent viewpoints to appreciate the geology and landscape of East Lothian.
History of Earth Sciences	Not applicable.
Economic geology	Former quarry on Skid Hill.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional	Excellent	Clough et al, 1910; Jackes, 1973; Sissons, 1975, Hall, 2012.	X

Site Geoscientific Value

The Garleton Hills are part of a suite of ice-moulded bedrock features characteristic of East Lothian. They form a fine example of ice-moulded lowland hills, with several crag and tail landforms and streamlined bedrock forms produced by glacial erosion.

The site is an excellent example of a glaciated escarpment and lowland forms of glacial erosion with regional significance.

Assessment of Site: Current site usage

Community	Hopetoun Hill is a popular walk and there is a footpath from Athelstaneford to the minor road near Yellow Craigs.
Education	It is unknown to what extent the site is used for education. It has potential to be used for school visits and local interest groups for education and interpretation of glacial landforms.

Assessment of Site: Fragility and potential use of the site

Fragility	The landforms are potentially sensitive to any large-scale quarrying, afforestation or tipping.
Potential use	School education and interpretation linking geology and landscape. Educational visits could be combined with visits to Whitekirk and North Berwick Law.

Geodiversity Summary

The site is a good example of an ice-moulded escarpment. There is significant potential for developing the geodiversity value of the site through the provision of geological information on-site as part of the existing countryside site interpretation and through engagement with local schools.

Site Photos

Photo ELC_22 P1: Dip slope of the Garleton Hills viewed from the south-east. © John Gordon.

Photo ELC_22 P2: View east along the Garleton Hills from Hopetoun Hill, showing a series of escarpments and channels between them. © John Gordon.

Photo ELC_22 P3: Garleton Hills. View north-west from Barney Hill showing streamlined bedrock forms. © John Gordon.

Photo ELC_22 P4: Craigy Hill crag and tail (centre) © John Gordon

ELC_23: Kidlaw Erratic

Site Information

Location and Summary Description:
The site comprises a glacially transported mass of limestone located north of Kidlaw Farm, 5 km south west of Gifford; this is the largest known glacial erratic in Scotland.

National Grid Reference: Mid-point: 350976, 664604	**Site type**: • Natural landform • Artificial quarry works
Site ownership: Kidlaw Farm	Current use: Agricultural land
Field surveyors: John Gordon	Current geological designations: None
Date visited: 27 September 2014	Other designations: None known

Site Map

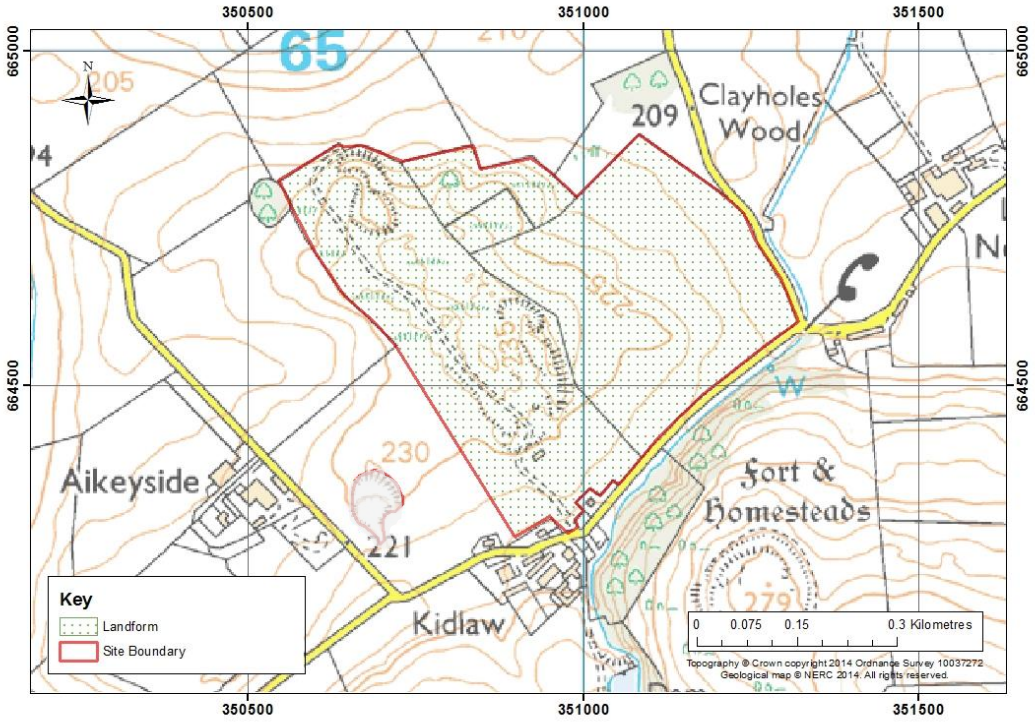


Figure 28: Kidlaw Erratic Location Map. The site boundary is drawn to include the main upstanding mass of limestone and its continuation below the adjacent moundy lower ground to the east as marked on the BGS 1:50k solid geology Sheet 33W. The site boundary for the Kidlaw Quarry (ELC_20) to the west is included for reference (shaded area).

Site Description

Background

The site is located north of Kidlaw Farm at the foot of the northern flank of the Lammermuir Hills (ELC_23 P1). Evidence of former quarrying and working of the limestone erratic at this site includes old lime kilns and quarry works.

Quaternary Deposits and Landforms

The erratic comprises a topographically upstanding mass of shattered Carboniferous limestone belonging to the Lower Limestone Group, c. 0.2km^2 in area surrounded by deposits of glacial till. It is the largest known glacial erratic in Scotland, transported during the Quaternary era. The shattered limestone is exposed in several disused quarries on the site (ELC_23 P3). It has been carried by ice several kilometers from source outcrops to the west or north west. Possibly the occurrence of a low escarpment with a long up-ice dip slope may have favoured the detachment and incorporation of the limestone mass beneath a cold-based part of the ice sheet. Kendall & Bailey (1908) noted two further, smaller examples of such rafts near Fala in Midlothian.

The limestone was formerly quarried and burned to produce lime, and the dilapidated lime kilns and disused quarries represent an industrial archaeological interest (ELC_23 P2).

Access and Additional Information

Access is via a gate and track into the field at Kidlaw Farm. There is limited parking on the roadside verge.

N.B. The disused rock quarry 170 m to the west of site is described separately within this audit.

Stratigraphy and Rock Types

Age: n/a	Formation: n/a
Rock type: n/a	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Access is from the minor road at Kidlaw Farm. The erratic can be easily viewed from the adjacent minor roads. Limited parking is available on the grass verge by the entrance track to the field.
Safety of access	A rough farm track crosses the site and there are additional animal tracks. Care is required on the rough ground, around the disused lime kilns and in the disused quarries.
Safety of exposure	Care is required in accessing the steep slopes in the northern quarry.
Access	Access is via agricultural land.
Current condition	The principal requirement is to maintain the overall visibility of the erratic landform both from outside and within the site, and the access to and visibility of the quarry exposures in the limestone. The former is good, but the sections are degraded and overgrown with limited exposure, and the slopes of the large northern quarry are now wooded.
Current conflicting activities	The area is used for grazing which is compatible with maintaining the visibility of the erratic mass.
Restricting conditions	The exposures in the disused pits are degraded and partly vegetated.
Nature of exposure	Disused artificial quarry works.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological &	History of lime production and presence of old lime kilns.

literary associations	
Aesthetic landscape	Limited value
History of Earth Sciences	Largest known glacial erratic in Scotland
Economic geology	History of lime production.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional/ National	Excellent	Kendall & Bailey 1908; Simpson, 1928; Jackes 1973; Sissons, 1975; Hall, 2012	X

Site Geoscientific Value

The site provides an excellent example of a large glacial erratic, the largest known in Scotland. The site is certainly of regional importance and a strong candidate for national importance because of its striking topographic expression. The Kidlaw Erratic complements the two glacial erratic features in the Quaternary of Scotland Geological Conservation Review at Leavad in Caithness and the Clochodrick Stone in Renfrewshire.

The Kidlaw Erratic is an excellent example of the glacial erosion and the transport of a large mass of bedrock: it is of regional to national significance.

Assessment of Site: Current site usage

Community	Local footpaths around the area may attract some walkers to this rural area.
Education	Currently probably little used, but has significant potential for education and public interpretation e.g. as an extension to the Hillfoots Trail.

Assessment of Site: Fragility and potential use of the site

Fragility	The site is potentially sensitive to development, dumping, natural overgrowth, tree planting and large-scale quarrying.
Potential use	School education, interpretation linking geological and industrial archaeology interests, and potential link to the Hillfoots Trail. Educational visits could be combined with visits to meltwater channels and deglaciation landforms south of Kidlaw at High Latch and elsewhere along the Lammermuir Hillfoots.

Geodiversity Summary

The site is an excellent example of a large glacial erratic with a striking topographic expression. It is relatively accessible and there is potential for developing the value of the site through promoting existing available information (e.g. East Lothian Landscapes [online]) and engagement with schools.

Site Photos

Photo ELC_23 P1: A glacially transported mass of mass of limestone forms a striking topographic feature north of Kidlaw Farm (centre). View from the south. © John Gordon.

Photo ELC_23 P2: Disused limestone kiln, Kidlaw. © John Gordon.

Photo ELC_23 P3: Disused limestone pit, Kidlaw. © John Gordon.

ELC_24: Lochhouses

Site Information

Location and Summary Description:
The site comprises a peat-filled depression in a gully system north of Lochhouses, 1.5km north-east of Whitekirk, that contains sedimentary evidence for a tsunami associated with the Holocene Storegga Slide that occurred offshore south-west Norway around 8110 years ago. It is an important dated reference site for this event in south-east Scotland.

National Grid Reference: Mid-point: 361415, 682176	**Site type**: • Natural landform • Sub-surface sediments
Site ownership: Not known	Current use: • Agricultural land
Field surveyors: John Gordon	Current geological designations: None
Date visited: 24th October 2014	Other designations: None

Site Map

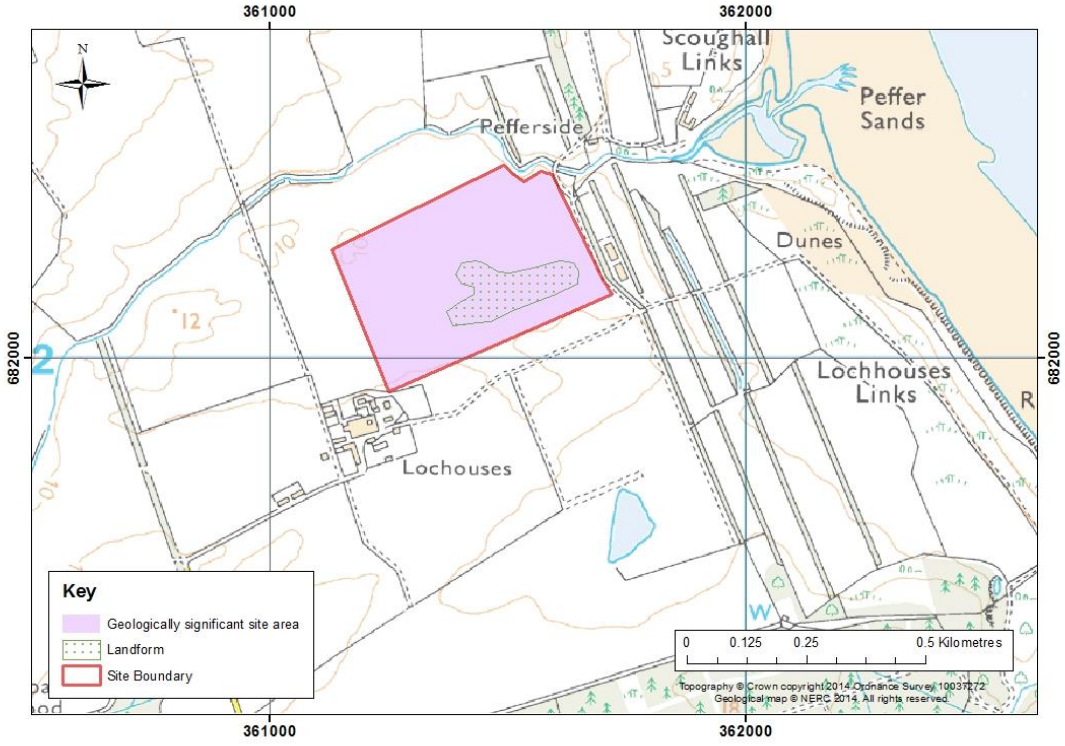


Figure 29: Lochhouses Location Map. Suggested site boundary includes the field boundary surrounding the landform in which the tsunami deposits are found.

Site Description

Background

The site consists of two buried gullies that join to form a peat filled depression cut off from the coast by blown sand north of Lochhouses (ELC_24 P1).

Quaternary Deposits and Landforms

Sub-surface coring has revealed that the gullies and depression are infilled with up to nearly 5 m of peat and fine clastic sediment. Within the peat, a layer of sand c. 30 cm thick contains marine and brackish-marine diatoms and damaged pollen grains (Robinson, 1982; Smith *et al*. 2004), indicative that the sand was washed inland. Four radiocarbon dates from the contacts of the sand with the peat place the accumulation of the sand within the timeframe of the Holocene Storegga Slide tsunami (c. 8110 years ago). This huge submarine slide is the most recent of a number of slides in the Storegga area off the coast of south-west Norway. It occurred over an area of 95,000 km^2 and involved the displacement of up to 3200 km^3 of sediment (Haflidason *et al*., 2004), generating a tsunami that impacted the eastern coast of Scotland from Shetland to the Borders (Smith *et al*., 2004).

Access and Additional Information

Access is across farmland from Lochhouses.

Stratigraphy and Rock Types

Age: n/a	Formation: n/a
Rock type: n/a	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Access is via Lochhouses Farm.
Safety of access	The site can be viewed from adjacent farm tracks.
Safety of exposure	There is no exposure.
Access	Access is via agricultural land.
Current condition	Good
Current conflicting activities	The area is used for agriculture which is compatible with maintaining the interest.
Restricting conditions	None evident.
Nature of exposure	Sub-surface sediments accessible only by coring.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	n/a
Aesthetic landscape	Near the coast
History of Earth Sciences	Evidence of tsunami hitting Scotland’s shores 8110 years ago.
Economic geology	n/a

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional	Good	Newey, 1965; Robinson, 1982; Shi 1995; Haflidason, 2004; Smith et al., 2004.	X

Site Geoscientific Value

Lochhouses is an important reference site for the Holocene Storegga Slide tsunami in south-east Scotland. A sand layer buried within peat provides sedimentary and dating evidence for the event.

Lochhouses is an important dated reference site for the Holocene Storegga Slide tsunami, with regional significance.

Assessment of Site: Current site usage

Community	Not applicable.
Education	Field use is principally as a research site.

Assessment of Site: Fragility and potential use of the site

Fragility	The site is potentially sensitive to building development, tree planting, tipping, drainage and deep ploughing.
Potential use	The site was first investigated in the 1960s and continues to have significant research value. There is also significant potential for virtual interpretation.

Geodiversity Summary

Lochhouses is an important research site for studies of the tsunami arising from the Holocene Storegga Slide around 8110 years ago.

Site Photos

Photo ELC_24 P1: Lochhouses viewed from north. The key sediments lie beneath the gully (centre of photo). © John Gordon.

ELC_25: Seacliff-Scoughall Shore

Site Information

Location and Summary Description:
The site comprises an ~3 km stretch of coast 5 km east of North Berwick with importance for the study of modern processes of shore platform development by storm wave action and weathering.

National Grid Reference: Mid-point: 361506, 684062 North-west end: 360255, 684864 South-east end: 362399, 682943	**Site type**: • Natural landform • Natural view
Site ownership: Partly Crown	Current use: Open country; agricultural land
Field surveyors: John Gordon	Current geological designations: Firth of Forth SSSI
Date visited: 24 October 2014	Other designations: Firth of Forth SPA and Ramsar site

Site Map

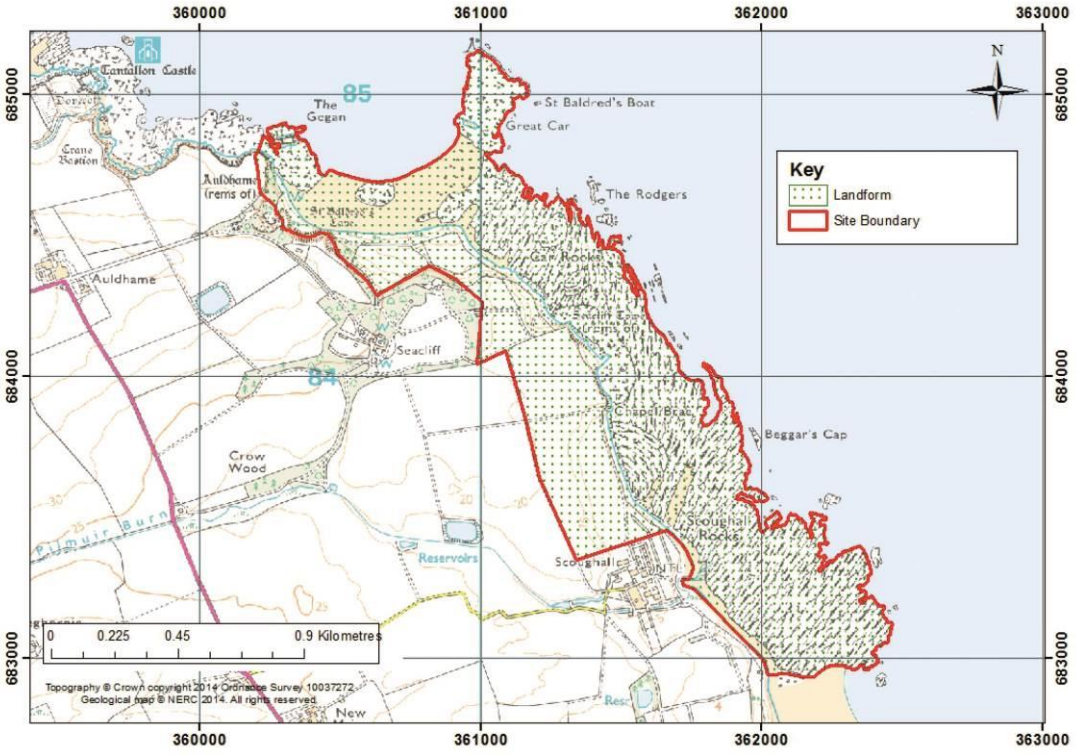


Figure 30: Seacliff-Scoughall Shore Location Map. The site boundary covers the landforms comprising shore platforms, backing cliffs, and postglacial raised beaches.

Site Description

Background

The site comprises a ~3 km stretch of coast with a well-developed intertidal shore platform located on a macro-tidal coast exposed to high wave energy from the north-east (ELC_25 P1, P4 and P6). The platform has an intermittent backing cliff and there are good examples of postglacial raised beaches and a higher-level shore platform. The site has been the focus of a detailed study by Hall (2011).

Quaternary Deposits and Landforms

The intertidal shore platform has been developed by planation of Carboniferous sandstone, siltstone, calcareous mudstone and dolomitic limestone of the Ballagan Formation and associated volcanic intrusive rocks (Davies et al., 1986; Hall, 2011). The lithology and structure of the bedrock strongly influence the morphology of the platform, as elsewhere in East Lothian (e.g. Dunbar). The intertidal shore platform formation probably pre-dates the last glaciation.

A variety of blocks are scattered across the surface of the platform (ELC_25 P6). They include basalt and metamorphic glacial erratics washed out from till. In addition, there are quarried joint blocks sourced from the seaward edge of the platform by the force of the waves and collapsed blocks from the weathering and erosional undercutting of weaker sedimentary rock layers on the surface of the platform (ELC_25 P2, P3 and P5). The production and movement of these blocks illustrate the processes that are currently shaping the platform and highlight the importance of wave action and weathering. Wave currents during storms have moved the blocks away from their areas of production towards the land, as indicated by imbricated boulder trails (ELC_25 P2) and the dislodging of blocks off rock pedestals. In storms over the last 40–240 years, blocks as large as 9 m^3 have been quarried from the platform's seaward edge and boulders of >5 m^3 have been moved landward over extensive areas of the platform, suggesting that wave current velocities in storms have probably reached 3–4 ms^{-1} in many places (Hall, 2011).

The importance of differential weathering and erosion of weaker rocks on the surface of the platform is indicated by the presence of basalt and sandstone boulders resting on calcareous mudstone pedestals (ELC_25 P7). East of Scoughall, the backing cliff in red sandstone displays a good example of cavernous (taffoni) weathering forms (ELC_25 P8).

Inland, there are good examples of Holocene raised beaches at Seacliff and north of Scoughall, backed by a relict cliff. Between Seacliff and Scoughall a higher platform is present above the relict cliff.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Ballagan Formation
Rock type: Sandstone, siltstone, calcareous mudstone and dolomitic limestone	
Age: Carboniferous	Formation: Southern Scotland Dinantian Plugs and Vents Suite
Rock type: Tuff and breccia	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	There is car parking at Seacliff Beach at the north of the site. Access is via a private road off the A198 east of North Berwick at Auldhame. There is a coin-operated entry barrier (£2.00 fee). There are toilets by the car park. Alternative access from the south is from Tyninghame Links car park.
Safety of access	The site is accessed by walking along the beach from Seacliff at low tide. Alternatively, it is possible to walk north along Ravensheugh Sands from Tyninghame, but the Peffer Burn must be crossed. Visitors should be aware of tide times when planning a visit to avoid the risk of being cut off by incoming tides.
Safety of exposure	Great care is required as the rocky shore platform is extremely slippery and there are loose rocks.

Access	The site is accessible from the car park at Seacliff.
Current condition	Good.
Current conflicting activities	None.
Restricting conditions	The main features are located in the intertidal area and therefore covered at high tide.
Nature of exposure	Intertidal shore platform, cliff exposures.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	Tantallon Castle is located to the west of the site. JMW Turner made several sketches of the cliffs and shore at Tantallon Castle, including 'Tantallon Castle and Bass Rock from the East' (1818) sketched from The Gegan (see < http://www.tate.org.uk/art/artworks/turner-tantallon-castle-and-bass-rock-from-the-east-d13598>).
Aesthetic landscape	Coastal landscape with views of the Bass Rock and Tantallon Castle.
History of Earth Sciences	Not known
Economic geology	Not known

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional/ National	Excellent	Hall, 2011, 2012	X

Site Geoscientific Value

Seacliff-Scoughall Shore is a good example of a shore platform, with excellent examples of rock weathering, erosional undercutting and block movement across the platform. The core value of the site lies in illustrating the combined role of modern wave processes and weathering on the erosion of an intertidal shore platform cut across a variety of rock types of different resistance on an exposed, macro-tidal coast. Representative examples of raised beaches and a higher shore platform also add to the interest and value of the site.

Seacliff-Scoughall Shore provides a variety of excellent examples of features related to shore platform development and is of regional to national importance. The site has significance for the study of modern processes of erosional coastal development.

Assessment of Site: Current site usage

Community	Seacliff is a popular beach. Most visitors probably do not proceed beyond the end of the beach.
Education	The site has good educational and research potential. However, safety of access is an issue for educational use. The area around The Gegan is most accessible for educational use (see <http://www.landforms.eu/Lothian/gegan.htm>)

Assessment of Site: Fragility and potential use of the site	
Fragility	The features are mainly formed in bedrock and are generally robust. They are dynamic and will evolve through natural processes of weathering and coastal erosion. The raised beached would be sensitive to development, waste tipping and tree planting.
Potential use	School education, research and on-line interpretation.

Geodiversity Summary

Seacliff-Scoughall Shore is important for the study of modern processes of shore platform development by storm wave action and weathering. It has potential for both education and further research.

Site Photos

Photo ELC_25 P1: Shore platform at The Gegan, Seacliff. © John Gordon.

Photo ELC_25 P2: Boulder train on the shore platform at The Gegan. © John Gordon.

Photo ELC_25 P3: Undercut collapsed blocks on the shore platform at The Gegan. © John Gordon.

Photo ELC_25 P4: Shore platform south of Great Scar. © John Gordon.

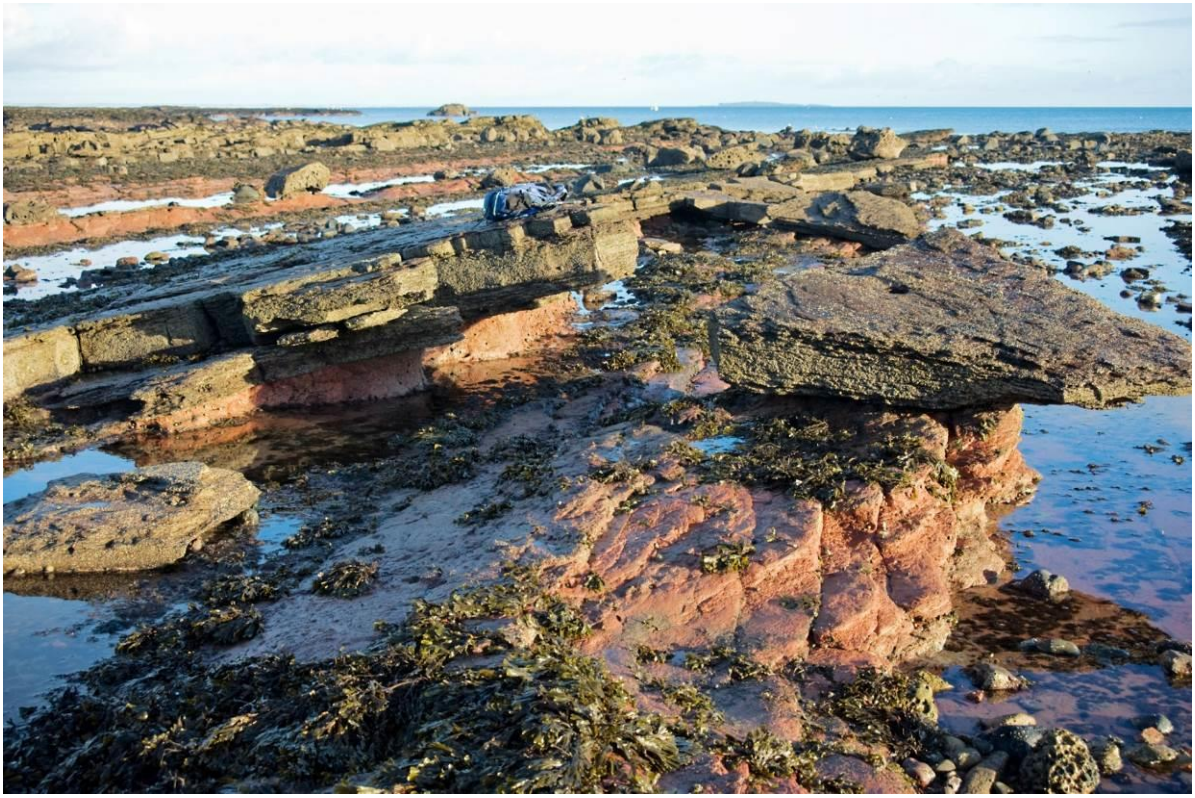


Photo ELC_25 P5: Undercut collapsed blocks on the shore platform south of Great Scar © John Gordon.

Photo ELC_25 P6: Shore platform with scattered boulders at Scoughall. © John Gordon.

Photo ELC_25 P7: Perched boulders (glacial erratics) on the shore platform at Scoughall © John Gordon.

Photo ELC_25 P8: Cavernous (taffoni) weathering in sandstone cliff east of Seacliff. © John Gordon.

ELC_26: Thorntonloch Coast

Site Information

Location and Summary Description:

The site comprises a 1 km stretch of coast 1 km south-east of Thorntonloch, including the intertidal shore platform and backing cliff. Good examples of natural arches are found in the more resistant sandstone headlands in the cliffs and the shore platform displays excellent 'karst-like' weathering features in calcareous sandstone.

National Grid Reference: Mid-point: 376110, 673220 North-west end: 375711, 673651 South-east end: 376579, 672892	**Site type**: • Natural landform • Natural view
Site ownership: Crown?	Current use: Open country
Field surveyors: John Gordon	Current geological designations: None
Date visited: 2 October 2014	Other designations: None

Site Map

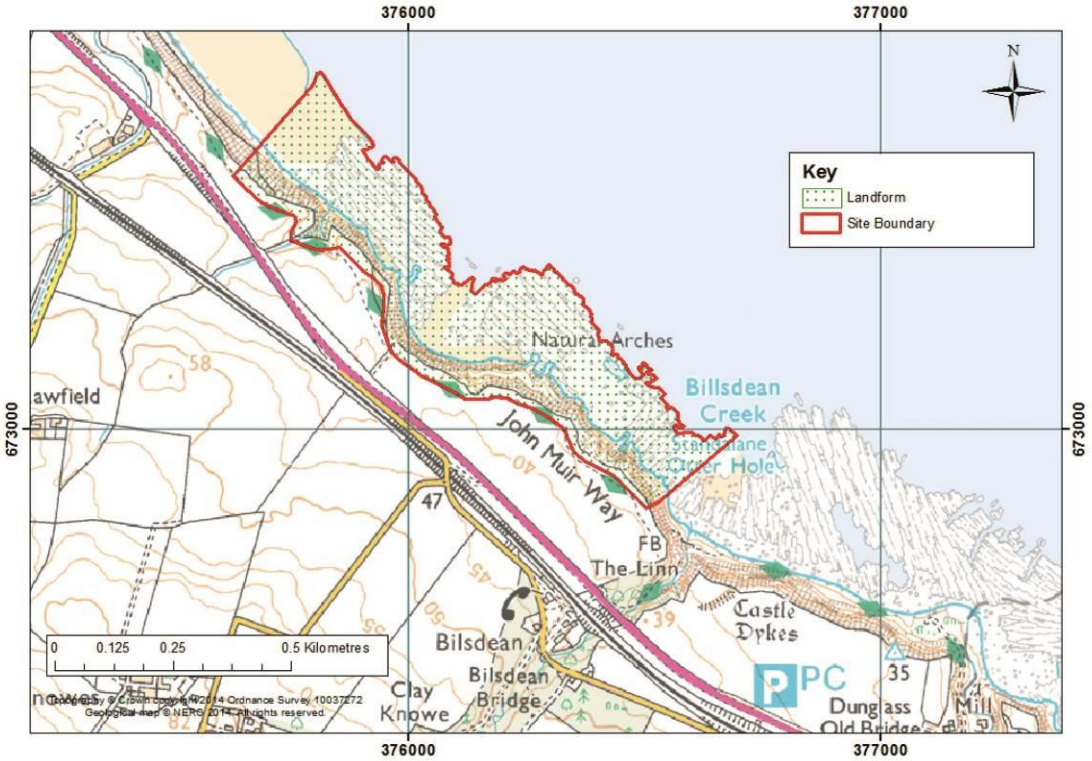


Figure 31: Thorntonloch Coast Location Map. The site boundary has been drawn to include the rock cliffs and intertidal shore platform.

Site Description

Background

The site lies c. 1 km to the south-east of Thorntonloch, and c. 400 m to the north-east of Bilsdean Bridge. The site includes both the rock cliffs and the adjacent intertidal shore platform along a 1 km stretch of coast, (ELC_26 P1).

Quaternary Deposits and Landforms

The rock coast landforms described in this section are developed across a sequence of Carboniferous sedimentary rocks, belonging to the Ballagan Formation (sandstone, siltstone and dolomitic limestone) and the Aberlady Formation (limestone). The site has two principal interests. The first is the presence of two natural arches eroded by the sea through two sandstone headlands (ELC_26 P2). The latter stand out into the sea since they are formed of more resistant red sandstone than the adjacent bedrock. Adjacent to the southern headland is a large former blowhole, now partly collapsed (ELC_26 P3).

The second interest is the range of weathering features present in the calcareous rocks composing the shore platform. These comprise a variety of solutional forms, similar to karst weathering, and include rinnenkarren, runnels, channels, pits and pedestals (ELC_26 P4, P5, P6, P7). The latter are particularly well developed on the seaward part of the platform (ELC_26 P8).

The weathering forms complement those developed in the limestone at Chapel Point in the nearby Barns Ness Coast SSSI.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Aberlady Formation
Rock type: Sandstones, siltstones, dolomitic limestones	
Age: Carboniferous	Formation: Ballagan Formation
Rock type: Limestone	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Access is from the car park at Thorntonloch approximately 1 km north of the site. Toilet facilities are available at the car park during the summer season (April- October). The John Muir Way passes along the top of the cliffs above the site.
Safety of access	The site is accessed by walking along the beach from Thorntonloch at low tide. Visitors should be aware of tide times when planning a visit to avoid the risk of being cut off by incoming tides.
Safety of exposure	Great care is required as the rocky shore platform is extremely slippery and there are loose rocks. The adjacent cliffs are unstable and visitors should not walk or stand underneath them, nor walk close to or under the arches.
Access	The site is accessible from the public car park at Thorntonloch. The John Muir Way passes through the site along the top of the cliffs.
Current condition	The cliffs and arches are clearly visible. Some of the weathering features are covered in algae, seaweed and barnacles.
Current conflicting activities	None known.
Restricting conditions	The weathering features are located in the intertidal area and therefore covered at high tide.
Nature of exposure	Vertical cliffs and intertidal shore platform.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	No known association
Aesthetic landscape	Coastal landscape (notwithstanding the presence of Torness Nuclear Power Station to the north).
History of Earth Sciences	The John Muir Way passes through the site.
Economic geology	No known association

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional	Good/ Excellent		X

Site Geoscientific Value

Thorntonloch Coast is a very good example of rock coast landforms in sedimentary rocks, including natural arches, a former blowhole and excellent weathering forms. The site has significant potential for research on rock coast weathering processes.

Thorntonloch Coast provides a very good example of distinctive rock coast landforms formed in calcareous sedimentary rocks and is of regional significance.

Assessment of Site: Current site usage

Community	Current usage is limited and most visitors probably do not proceed beyond the end of the sandy beach. The arches are visible from the John Muir Way which passes above the site. The larger weathering features on the seaward part of the shore platform are also visible from the footpath at low tide.
Education	The site has good educational and potential research potential for its weathering features. However, safety of access is an issue for educational use.

Assessment of Site: Fragility and potential use of the site

Fragility	The features are formed in bedrock and are generally robust. They are dynamic and will evolve through natural processes of weathering and coastal erosion.
Potential use	Research, possible interpretation linked to the John Muir Way, but note safety issues.

Geodiversity Summary

The site displays good examples of natural arches and an excellent suite of weathering forms developed in calcareous sedimentary rocks. The latter have potential for research on the processes of coastal weathering and erosion.

Site Photos

Photo ELC_26 P1: Thorntonloch Coast showing northern-most red sandstone headland with natural arch (1) and shore platform with main area of weathering features (2). View looking south-east from the John Muir Way © John Gordon.

Photo ELC_26 P2: Natural arch and stack in sandstone, northern headland. Photo looking to the north. © John Gordon.

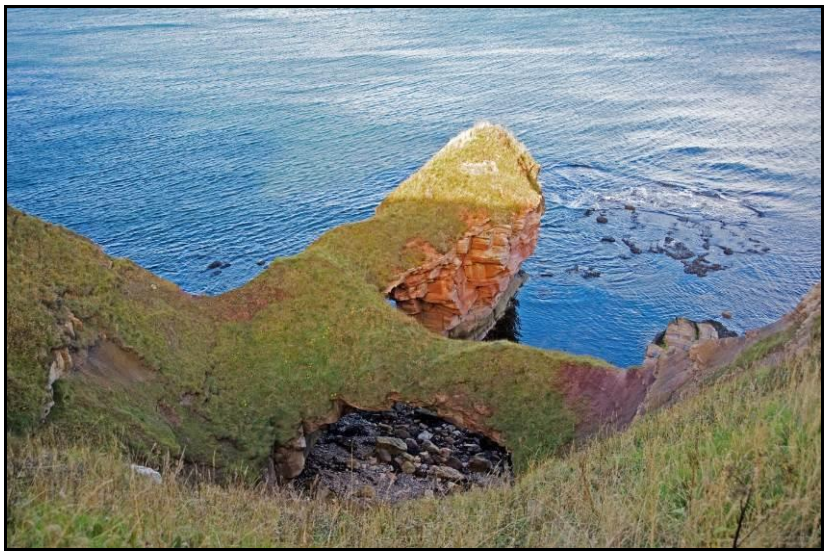


Photo ELC_26 P3: Former partly collapsed blowhole and arch, southern headland. Photo looking north. © John Gordon.

Photo ELC_26 P4: Solutional channels on the shore platform**.** © John Gordon.

Photo ELC_26 P5: Solutional weathering pits on intertidal platform, with beige rounded concretions in the upper part of the image (these are more resistant to weathering than the rock surrounding them)**.** © John Gordon.

Photo ELC_26 P6: Runnels and solutional weathering near the seaward edge of the intertidal rock platform**.** © John Gordon.

Photo ELC_26 P7: Differential weathering under a 'caprock' calcretion in the sandstone**.** © John Gordon.

ELC_27: Whitekirk

Site Information

Location and Summary Description:
The site comprises an area of streamlined bedrock characteristic of the ice-moulded lowlands of East Lothian.

National Grid Reference: Mid-point: 358181, 681015 West-end: 357286, 680808 East-end: 359095, 681580	**Site type**: • Natural landform • Natural view
Site ownership: Local land owners	Current use: Agricultural land
Field surveyors: John Gordon	Current geological designations: None
Date visited: 26 September 2014	Other designations: None known

Site Map

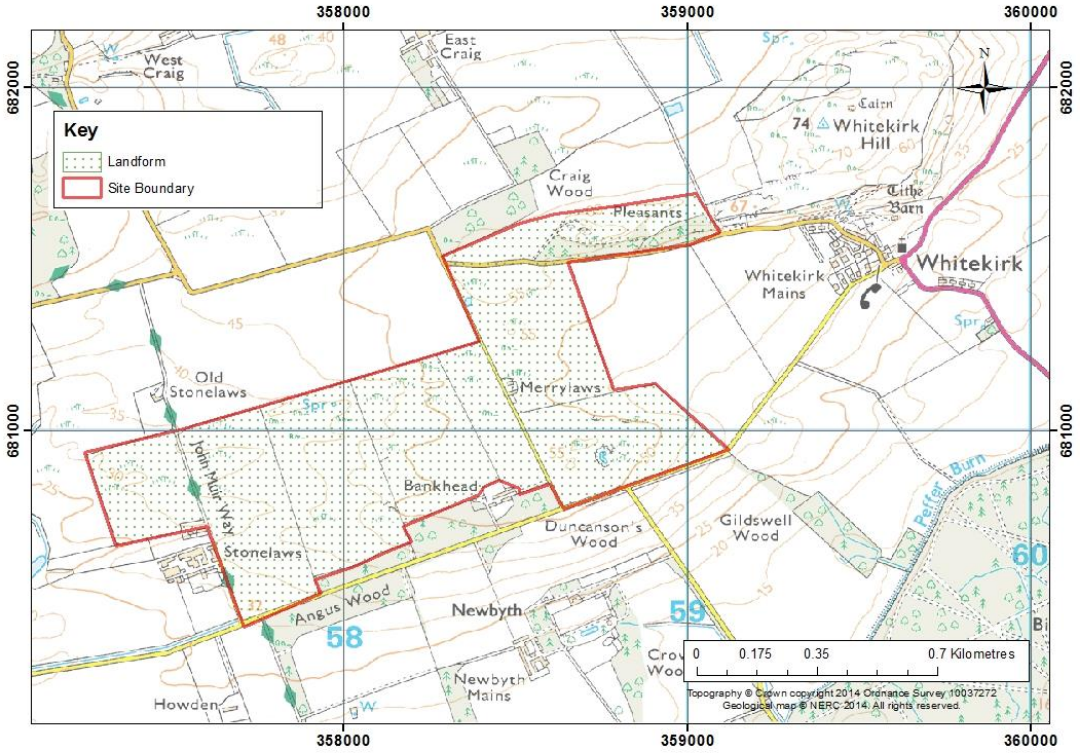


Figure 32: Whitekirk Location Map. The site boundary is drawn to include a representative area of ice-moulded bedrock.

Site Description

Background

The site (approximately 1.5 km long) is located west of the village of Whitekirk, c. 3 km to the north of East Linton.

Quaternary Deposits and Landforms

Glacial erosion has produced extensive moulding and streamlining of the basaltic bedrock (belonging to the Garleton Hills Volcanic Formation) at the site. This erosion has formed low, elongated rock ridges (tens to hundreds of metres long, and a few metres to tens of metres high) separated by bedrock grooves (ELC_27 P1 and P2). These are particularly well developed between Stonelaws and Merrylaws, where some of the ridges appear as uncultivated areas in the fields (ELC_27 P3). The ridges are broadly parallel and aligned between ENE-WSW. Similar features are well developed on Whitekirk Hill where the alignment of the fairways on the golf course follows the grooving of the bedrock between the ridges. A good example of glacially abraded basalt with striated rock surfaces occurs near the old quarry at Merrylaws (Hall, 2012).

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Mugearite, basalt.	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Whitekirk is accessible from the A198 south from North Berwick or via the A1/A199 from Edinburgh. The landforms can be easily viewed from the minor roads and footpaths that cross the area.
Safety of access	Care is required parking on roadside verges.
Safety of exposure	Not applicable.
Access	Access is via agricultural land. The site can be viewed from the minor roads and footpaths that cross the area.
Current condition	The principal requirement is to maintain the overall visibility of the landforms. The current condition of the features is generally good.
Current conflicting activities	The area is used for agriculture which is generally compatible with maintaining the visibility of the landforms.
Restricting conditions	Some of the rock outcrops are obscured by vegetation growth, notably the ice-abraded surfaces at Merrylaws.
Nature of exposure	Landscape feature, glacial landforms.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	No known association
Aesthetic landscape	Limited value
History of Earth Sciences	The John Muir Way passes through part of the site.
Economic geology	Former quarry to the south-east of Merrylaws – use unknown.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional	Good	Kendall & Bailey, 1908; Jackes, 1973; Sissons, 1975; Hall, 2012.	X

Site Geoscientific Value

The Whitekirk site is a good representative area of ice-moulded bedrock characteristic of lowland East Lothian. East Lothian is a particularly good example of an ice-moulded lowland.

The Whitekirk site is a good example of lowland glacial erosion producing streamlined bedrock ridges and is of regional significance.

Assessment of Site: Current site usage

Community	Likely limited value – possible daily usage along John Muir Way during peak season.
Education	Currently probably little used, but has some potential for education and public interpretation e.g. the John Muir Way crosses the site.

Assessment of Site: Fragility and potential use of the site

Fragility	Waste tipping, the likelihood of development and extensive tree planting would affect the quality and visibility of landforms at the site.
Potential use	School education, interpretation linking geology and landscape. Educational visits could be combined with visits to the Garleton Hills and North Berwick Law.

Geodiversity Summary

The Whitekirk site is a good representative example of an ice-moulded lowland area, demonstrating streamlined bedrock formed by glacial erosion. It is relatively accessible and there is potential for developing the value of the site through promoting existing available information and engagement with schools.

Site Photos

Photo ELC_27 P1: Streamlined ridge at Pleasants west of Whitekirk. View to the south. © John Gordon.

Photo ELC_27 P2: Streamlined ridge east of Merrylaws. View to the south. © John Gordon.

Photo ELC_27 P3: Ice-moulded bedrock near Stonelaws (right), view to the south © John Gordon.

ELC_28: Tyne Estuary & Belhaven Bay

Site Information

Location and Summary Description:
The Tyne Estuary & Belhaven Bay site is notable for a varied assemblage of dynamic coastal landforms located west of Dunbar. The main features are sand spits, intertidal sand flats, sand dunes, salt marshes, shore platforms, raised shorelines and a tsunami deposit.

National Grid Reference: Mid-point: 364408, 679790 North-west end: 363636, 681113 South-east end: 366149, 678563	**Site type**: • Natural landform • Natural view
Site ownership: Not known	Current use: Open country
Field surveyors: John Gordon	Current geological designations: Part of the site lies in the Dunbar GCR site
Date visited: 2 December 2014	Other designations: Firth of Forth SSSI, SPA and Ramsar site; John Muir Country Park.

Site Map

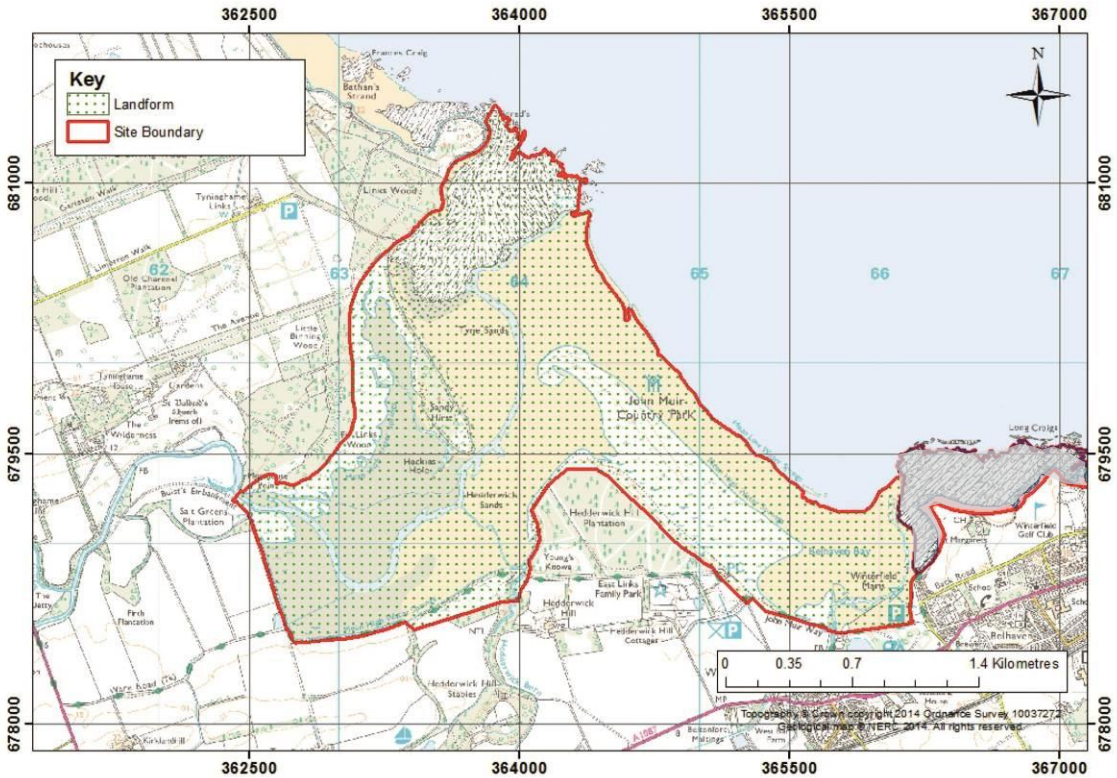


Figure 33: Tyne Estuary Map. The site boundary includes the landform assemblage of the modern estuary and bay as an integral coastal geomorphology unit. The adjacent bedrock and Quaternary site at Dunbar (ELC_4) is shown for reference (transparent grey area).

Site Description

Background

The site comprises a varied assemblage of coastal landforms, including sand spits, sand dunes, salt marshes, intertidal sand flats, raised shorelines and a tsunami deposit all developed in a highly dynamic environment (ELC_28 P1). Aspects of the coastal evolution, including its wider setting in the context of the deglaciation of the area, are described by Jackes (1973), Rose (1980), Davies et al. (1986), Firth et al. (1997) and Babtie Group ABP Research & Consultancy Ltd (2002). Jackes (1973), Davies et al. (1986) and Firth et al. (1997) provide geomorphological maps of varying detail.

Quaternary Deposits and Landforms

Shore platforms and raised beaches

The east side of Belhaven Bay displays an assemblage of former shorelines represented by shore platforms and raised beach deposits. A shore platform in the present intertidal zone is cut across gently dipping Carboniferous strata and continues more extensively to the east (see ELC_4 Dunbar Shore). At the back of the present beach, there is a low cliff and a step up to a second (raised) shore platform overlain by a Holocene raised beach that is utilised by the Winterfield Golf Course (ELC_28 P2, P3). Inland to the east, the backing cliff of this platform rises to a higher glaciated shore platform. Good sections in the raised beach deposits reveal shelly sand and gravel deposits (ELC_28 P3). However, some of the exposures have been covered by coastal defence works (concrete blocks and gabion baskets that are partly collapsing). Hall (2012) notes that the coastal edge has retreated by some 45 m in this area since AD 1854, indicating significant coastal erosion of the soft bedrock cliff. On the Tyninghame shore, an extensive intertidal shore platform also fringes the bay north-east of Sandy Hirst towards St Baldred's Cradle. The platform here is extensively littered with glacial erratics (ELC_28 P4).

Sections in raised beach deposits and blown sand exposed by recent coastal erosion also occur along the south side of the Tyne Estuary near Hedderwick and along the lower part of the incised Hedderwick Burn (Davies et al., 1986). The presence here of gravel layers with rip-up clasts of mud and broken shells may also represent deposits of the tsunami associated with the Holocene Storegga Slide (Hall, 2012; Smith et al., 2012); see also ELC_23 (Lochhouses).

Beach-dune-saltmarsh complexes

The site forms a large sediment sink with significant accumulations of sand in the extensive intertidal sandflats within the Tyne Estuary and the adjacent sand dune systems and sandy beaches (ELC_28 P1). The site is of particular interest for the two sand spits of Sandy Hirst and Spike Island (ELC_28 P1). Sandy Hirst extends south from the north shore of the estuary. It appears to have been a relatively stable feature since first recorded on Ordnance Survey maps in 1853 (Jackes, 1973). On its west side, an extensive area of saltmarsh fringes the bay (ELC_28 P5). Saltmarsh is also present along the south-west margin of the site in front of Buist's Embankment.

Spike Island is a relatively recent recurved spit formed by coastal progradation through the growth and attachment of an offshore sandbank sometime after the 1940s (Jackes, 1973). A line of sand dunes has built up along the spit and an area of saltmarsh is developing on the former sandflats on its landward side (ELC_28 P1, P6). Inland of these saltings, a line of older dunes marks the former coastal edge. The southern part of the present coastal edge of Spike island is relatively low and appears relatively stable, whereas the seaward edge of the higher dunes towards the north end is cliffed and eroding (ELC_29 P7).

Additional Information

The wider geomorphological setting of the site comprises Lateglacial and Holocene raised beach deposits and a range of glacifluvial landforms and deposits that extend inland from the estuary into adjacent areas of predominantly agricultural land (Jackes, 1973; Davies et al., 1986; Firth et al., 1997). These adjacent features have not been included here, but could be evaluated as part of a revised site assessment in the future.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Ballagan Formation
Rock type: Sandstone, siltstone and dolomitic limestone	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Access to the southern part of the site is from the A1 via the A1087 to Dunbar. There are public car parks and toilets at the John Muir Country Park access points at Belhaven and Linkfield. Access to the northern part of the site is from the A1 via the A199, A198 and the unclassified road (Limetree Walk) to the Tyninghame Links car park.
Safety of access	No additional precautions beyond those normally associated with visiting a beach and dunes. Visitors should be aware of incoming tides if accessing the beach and intertidal flats and should note that the Belhaven bridge is not accessible at high tide.
Safety of exposure	No special precautions are required.
Access	There is good access on footpaths.
Current condition	The condition is good.
Current conflicting activities	None known.
Restricting conditions	The active sand spit and intertidal areas are covered at high tide. Seasonal access restrictions may apply over parts of the site during the bird breeding season.
Nature of exposure	Coastal

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	No known associations
Aesthetic landscape	Coastal landscape
History of Earth Sciences	The John Muir Way passes the site.
Economic geology	No known associations

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional	Excellent		X

Site Geoscientific Value

The Tyne Estuary & Belhaven Bay site displays an excellent suite of coastal landforms and sedimentary environments that demonstrate coastal evolution during the Quaternary, particularly during the latter part of the Holocene, and support a diversity of coastal habitats. There is significant potential for research on past and present processes of coastal evolution, as well as for education and public interpretation on coastal evolution and the links between geodiversity and biodiversity.

The Tyne Estuary & Belhaven Bay is an excellent regional example of an assemblage of dynamic coastal landforms and sedimentary environments.

Assessment of Site: Current site usage	
Community	The area is heavily used for recreation, including walking and birdwatching.
Education	There is significant potential for education and public interpretation on coastal dynamics and evolution.

Assessment of Site: Fragility and potential use of the site	
Fragility	The site would be vulnerable to heavy trampling, off-road vehicle use, tree planting, tipping and coastal protection works.
Potential use	School education and public interpretation addressing coastal dynamics and living with a dynamic landscape in the context of climate change and sea-level rise; research on modern coastal dynamics and sedimentary processes; monitoring coastal changes.

Geodiversity Summary

The site is an excellent example of a range of active coastal landforms and there is significant potential for research on coastal dynamics and developing its educational value and public interpretation through greater promotion of existing information.

Site Photos

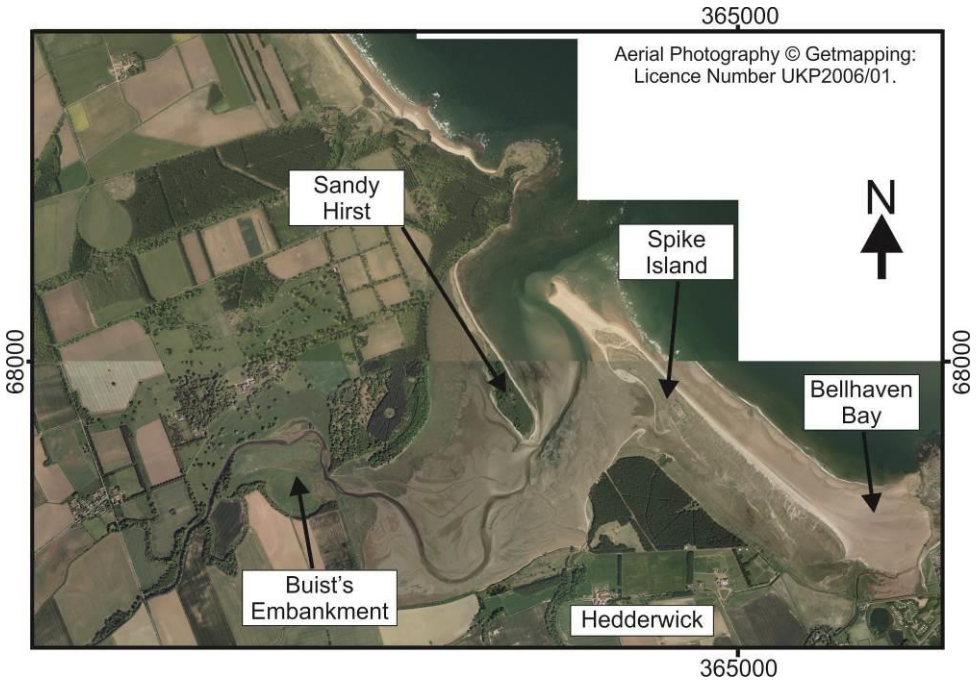


Photo ELC_28 P1: Satellite image showing the diversity of geomorphological features present.

Photo ELC_28 P2: East side of Belhaven Bay, showing the intertidal shore platform, low backing cliff and raised shore platform with raised beach deposits on top now occupied by Winterfield Golf Course. The section in raised beach deposits in the foreground is shown in Photo 3. © John Gordon.

Photo ELC_28 P3: Section in raised beach deposits resting on a raised shore platform planed across dipping mudstone and cementstone at Belhaven. © John Gordon.

Photo ELC_28 P4: Intertidal shore platform littered with glacial erratics, north of Sandy Hirst.© John Gordon.

Photo ELC_28 P5: Saltmarsh on the west side of Sandy Hirst. © John Gordon.

Photo ELC_28 P6: Saltmarsh development between Spike Island spit (left) and the former coastal edge marked by the line of sand dunes (right). © John Gordon.

Photo ELC_28 P7: Present coastal edge of Spike Island. © John Gordon.

ELC_29: Gullane Bents

Site Information

Location and Summary Description:
Gullane Bents is a 2km long stretch of sand dunes and beach located to the west of the town. It is of geomorphological interest as an applied case study of sand dune restoration following extensive disturbance.

National Grid Reference: Mid-point: 347961, 683605 West-end: 347349, 683285 East-end: 348306, 683907	**Site type**: • Natural landform
Site ownership: Crown, East Lothian Council	Current use: Open country; recreational land.
Field surveyors: John Gordon	Current geological designations: Firth of Forth SSSI
Date visited: 5 November 2014	Other designations: Firth of Forth SPA, Ramsar

Site Map

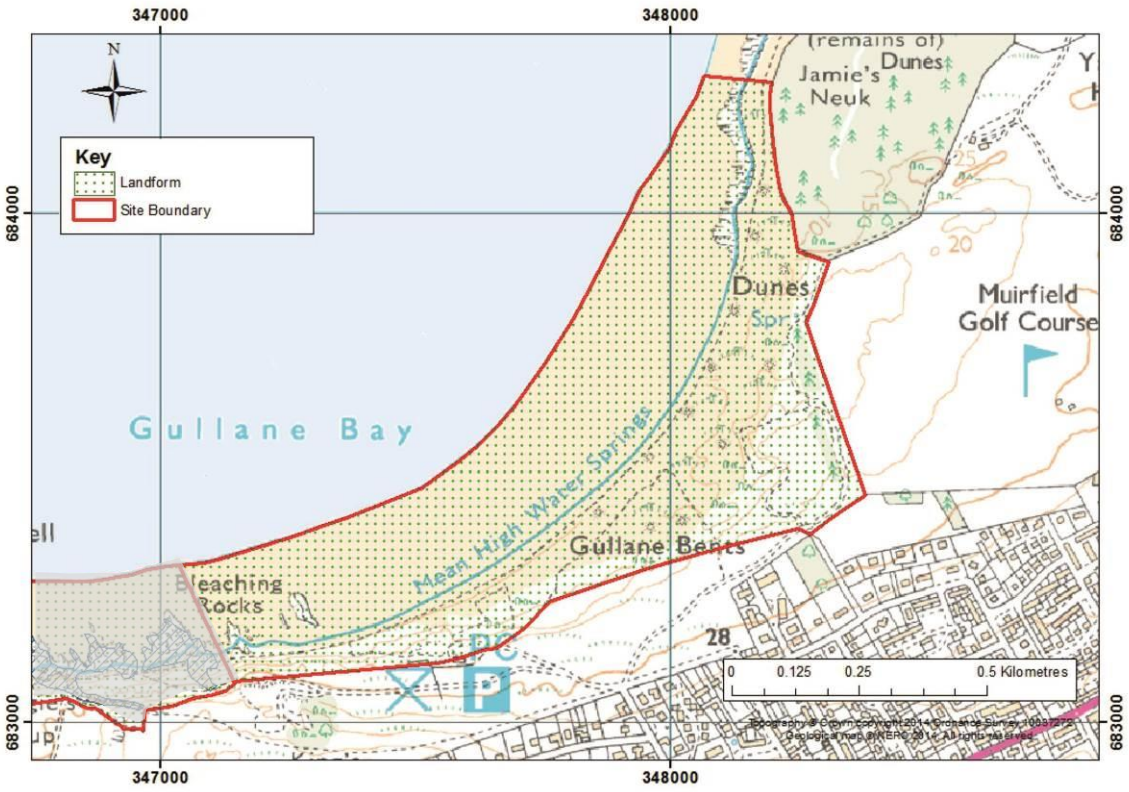


Figure 34: Gullane Bents Map. The site boundary includes the sand flats of Gullane Bay, the Gullane Bents dune system and backing cliff. The site boundary for the adjacent Gullane Shore bedrock/Quaternary site (ELC_13) to the west is included (ELC_30) (transparent grey polygon). It should be noted that the westernmost extent of the sand flats at Gullane Bay is included within the adjacent Gullane Shore site (ELC_13) but is considered to be integral with the sand flat - dune system of Gullane Bents.

Site Description

Background

The site comprises an area of sand dunes and beach on the north-west side of Gullane. The dunes overlie a raised beach with a backing cliff inland (ELC_29 P1, P2). Prior to World War 2, the area was heavily used for recreation and sand extraction. During the War, the beach and dunes were used for military exercises. Consequently, there was a high human impact, with extensive areas of bare sand and sand blowing landwards. During the 1960s, the Council implemented a rehabilitation plan that included the re-creation of the foredune ridge, use of fences to trap sand and planting of marram grass and sea buckthorn to stabilise bare sand areas and sources of blowing sand in the westernmost dunes. As part of the works, the foredune was bulldozed and re-profiled.

Quaternary Deposits and Landforms

A detailed description of the geomorphology of Gullane Bents is provided by Rose (1980). The central part of the bay is fronted by a single low foredune ridge with a duneslack behind, then an area of climbing dunes on the backing cliff. A zone of more complex high dunes occurs to the north-east (ELC_29 P3).

Sand dunes probably began to form along the East Lothian coast after the retreat of the last ice sheet in places where there was an abundance of sand derived from glacifluvial sediments. This material has been reworked by wind and sea during the Holocene. As relative sea level rose during the early part of the Holocene, large quantities of sand moved shorewards. The sand was blown inland, forming climbing dunes on the rising topography. As relative sea level subsequently fell, the sand dune system extended seawards.

The Babtie Group ABP Research & Consultancy Ltd. (2002) report summarises the main changes over the last few centuries. Net erosion has generally exceeded accretion over the last hundred years as a result of human impacts and natural processes, accompanied by steepening of the beach. Predominant wave directions from northeast and east result in westerly sand movement, reflected in accretion at the west end of the bay. Between 1907 and 1999, the Babtie Group ABP Research & Consultancy Ltd. (2002) estimated maximum coastal recession of 40 m from comparison of OS maps.

Along much of the length of the bay, apart from the western end, the coastal edge of the foredune ridge is currently undercut by the sea, particularly in winter, with collapse of sea buckthorn plants down the seaward face, a similar situation to that noted by Rose in 1980 (ELC_29 P4, P5). Behind the dunes, a bare sand plain in 1980 has become stabilised. The foredune ridge is relatively low in places, with local washovers occurring during winter 2013-2014 (ELC_29 P5, P6), and may be vulnerable to future breaching under a combination of sea-level rise and storm surge conditions.

The dunes formed under conditions of abundant sediment supply, conditions that no longer exist. Contemporary dune formation and maintenance are therefore limited by low sand supply. A likely future scenario under rising sea levels and increasing magnitude and/or frequency of storm events involves erosion and onshore migration of the coastal edge, washovers and possibly breaching of the foredune barrier and dune blowouts (Babtie, 2002).

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Access is along a minor road (Sandy Loan) in Gullane off the A198 coastal road east from Edinburgh. There is a public car park and toilets.
Safety of access	No additional precautions beyond those normally associated with visiting a beach and dunes.
Safety of exposure	No special precautions are required.
Access	There is good access on footpaths from the public car park at Gullane Bents.
Current condition	The condition is good.
Current conflicting	None known.

activities	
Restricting conditions	The cover of sea buckthorn restricts views of the inland dunes.
Nature of exposure	Beach, coastal.

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	WWII – military exercises were undertaken in the area.
Aesthetic landscape	Coastal landscape
History of Earth Sciences	No known association
Economic geology	Sand extraction prior to WWII.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional	Good	Rose, 1980; Babtie Group ABP Research & Consultancy Ltd., 2002.	X

Site Geoscientific Value

Gullane Bents has been the subject of a major sand dune restoration programme. There is significant potential for education and public interpretation on coastal dynamics associated with human impacts and natural processes, particularly in a context of climate change. The large amount of documentary evidence makes it a particularly good case study of coastal changes under natural processes and human impacts.

Gullane Bents is a good example of sand dune restoration, with regional significance.

Assessment of Site: Current site usage	
Community	The beach and dunes are heavily used for recreation.
Education	There is significant potential for education and public interpretation on coastal dynamics associated with human impacts and natural processes.

Assessment of Site: Fragility and potential use of the site	
Fragility	The site is vulnerable to heavy trampling, off-road vehicle use, tree planting, hard engineering responses to coastal erosion, waste tipping and potential development.
Potential use	School education and public interpretation addressing coastal dynamics and living with a dynamic landscape in the context of climate change and sea-level rise.

Geodiversity Summary

The site is a good case study of sand dune restoration and there is potential for developing its educational value and public interpretation through promoting existing available information and historical material held by East Lothian Council.

Site Photos

Photo ELC_29 P1: Gullane Beach and Bents: view from the south-west, showing erosion of much of the coastal edge and a small area of accretion at the back of the beach in the foreground. © John Gordon.

Photo ELC_29 P2: Gullane Bents: view from the north-east showing the foredune ridge, dune slack and climbing dunes on the backing cliff © John Gordon.

Photo ELC_29 P3: Gullane Bents: view from the car park, showning the foredune ridge, dune slack and area of high dunes to the north-east. © John Gordon.

Photo ELC_29 P4: Eroding coastal edge. © John Gordon.

Photo ELC_29 P5: Washover of the foredune ridge. © John Gordon.

Photo ELC_29 P6: Washover areas along the foredune ridge. © John Gordon.

ELC_30: Aberlady Bay

Site Information

Location and Summary Description:
Aberlady Bay comprises a varied assemblage of coastal landforms located north of the village of Aberlady. It includes sand dunes, salt marsh, extensive intertidal flats, an active sand spit and raised shorelines.

National Grid Reference: Mid-point: 346004, 681262	**Site type**: • Natural landform • Natural view
Site ownership: Mostly Local Nature Reserve (East Lothian Council); part owned by local golf courses	Current use: Open country, recreation
Field surveyors: John Gordon	Current geological designations: Part of Firth of Forth SSSI
Date visited: 5 November 2014	Other designations: Firth of Forth SPA and Ramsar site, Aberlady Bay Local Nature Reserve

Site Map

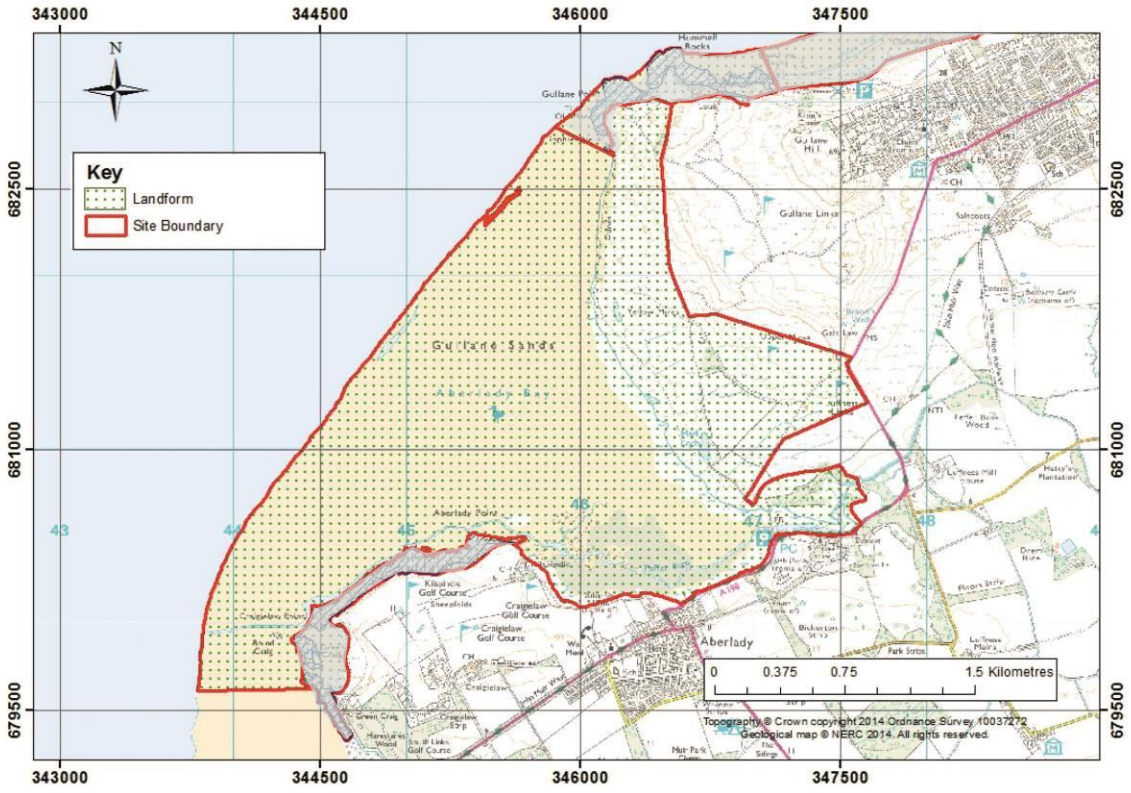


Figure 35: Aberlady Bay Map. The site boundary has been drawn to include the dominant intertidal portion of Aberlady Bay including sand flats, and the dune system. The site boundary is largely coincident with that of the Aberlady Bay Local Nature Reserve. The neighbouring bedrock/Quaternary ELC Geodiversity sites (ELC_13, Gullane and ELC_14, Kilspindie Shore) are included for reference, along with the geomorphological Gullane Bents (ELC_29) site, shown as transparent greyed out areas.

Site Description

Background

The site comprises an area of sand dunes, salt marsh, intertidal sand and mud flats, an actively forming sand spit and raised shorelines (ELC_30 P1). Different aspects of the geomorphology and coastal evolution are described by Smith (1972), Rose (1989), Firth et al (1997), Kirby (1997) and Babtie Group ABP Research & Consultancy Ltd. (2002).

Quaternary Deposits and Landforms

Several relict erosional coastal features occur within the site. Kirby (1997) identified fragments of two raised shore platforms at Gullane Point, while Smith (1972) described a buried planated till surface at 1.8 m OD between the village of Aberlady and the footbridge at the entrance to the Local Nature Reserve. Intertidal shore platforms are present at Gullane Point and Aberlady Point, planed across a variety of dipping Carboniferous strata. Glacial erratic blocks are present on their surface (ELC_30 P2).

Smith (1972) identified two raised Holocene shorelines at 8-9 m OD and 6-7 m OD on the southern flank of Gullane Hill within Luffness Links Golf Course (ELC_30 P3). From radiocarbon dates on peat, Smith concluded that all the deposits below 6 m OD formed in the last c. 2500 years.

Running south from Gullane Point, a succession of dune ridges and intervening dune slacks form part of a prograding coastal foreland that has built westwards during the late Holocene from the lower slopes of Gullane Hill (Rose, 1980; ELC_30 P4). According to Kirby (1997), a series of five sand spits formed south of Gullane Point, with dunes subsequently accumulating on their surfaces under conditions of abundant sediment supply. The present sand spit is the latest in the sequence reflecting a net southward movement of sand that has also diverted the Peffer Burn southwards. Analysis of coastal changes on Ordnance Survey maps indicates that much of the shoreline of Aberlady Bay underwent accretion between 1907 and 1999 (Babtie Group ABP Research & Consultancy Ltd, 2002). The present coastal dune edge along the beach south of Gullane Point is vegetated but relatively steep-fronted, suggesting wave erosion at the base (ELC_30 P5).

Aberlady Bay itself is a large sediment sink with extensive intertidal sand and mudflats fringed by salt marshes (ELC_30 P6, P7). As noted by Firth et al. (1997), those on the southern margins of the bay are fronted by a small cliff and undergoing erosion (ELC_30 P6).

There are close associations between the different landforms, vegetation and the diversity of physical features which provide the basis for a range of habitats and vegetation communities (Kirby, 1997). The salt marsh and intertidal flats also form important wintering grounds for geese.

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Access is from the A198 coastal road east from Edinburgh at Aberlady. There is a public car park and toilets 500 m east of the village and a footbridge across the Peffer Burn at the entrance to the Local Nature Reserve. Access to the southern shore of the bay can be gained by walking along the road from Aberlady to Kilspindie Golf Course. The site can also be accessed by walking along the coast from Gullane.
Safety of access	No additional precautions beyond those normally associated with visiting a beach and dunes. Visitors should be aware of incoming tides if accessing the sand spit and intertidal flats.
Safety of exposure	The tide rapidly rises in the intertidal flats and visitors should be aware of tide times.
Access	There is good access on footpaths from the public car park 500m east of Aberlady. Part of the site lies within a golf course adjacent to the Local Nature Reserve.
Current condition	The condition is good.
Current conflicting activities	None known.
Restricting conditions	The active sand spit and intertidal areas are covered at high tide. Seasonal access restrictions may apply over parts of the Local Nature Reserve during the bird breeding season.

Nature of exposure	Coastal

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	Not known
Aesthetic landscape	Coastal landscape
History of Earth Sciences	The John Muir Way passes through part of the site
Economic geology	Not known

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Litho Stratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology				
Structural Geology				
Palaeontology				
Geomorphology	Regional	Good/ Excellent	Smith (1972), Rose (1980), Firth et al (1997), Kirby (1997), Babtie Group ABP Research & Consultancy Ltd (2002)	X

Site Geoscientific Value

Aberlady Bay displays a good range of coastal landforms and sedimentary environments that demonstrate coastal evolution, particularly during the latter part of the Holocene. There is significant potential for research on coastal processes and coastal evolution, as well as education and public interpretation on coastal dynamics and the links between geodiversity and biodiversity.

Aberlady Bay is an excellent example of an assemblage of depositional coastal landforms and sedimentary environments with regional significance.

Assessment of Site: Current site usage

Community	The beach and dunes within the Local Nature Reserve are heavily used for recreation, including walking and bird watching. The area includes parts of the Luffness Links and Gullane Links golf courses.
Education	There is significant potential for education and public interpretation on coastal dynamics and evolution.

Assessment of Site: Fragility and potential use of the site

Fragility	Trampling, off-road vehicle use, tree planting, tipping and hard engineering responses to coastal erosion; likelihood of development. However the site is carefully managed as a Local Nature Reserve by East Lothian Council. Note that coastal erosion is part of the natural process of coastal evolution.
Potential use	School education and public interpretation addressing coastal dynamics and living with a dynamic landscape in the context of climate change and sea-level rise.

Geodiversity Summary

The site is a good example of a range of coastal landforms and there is potential for developing its value for research, education and public interpretation through greater promotion of existing information.

Site Photos

Photo ELC_30 P1: View north across Aberlady Bay from Kilspindie on the south shore. © John Gordon.

Photo ELC_30 P2: Glacial erratic block on an intertidal shore platform near Gullane Point. The platform is cut across dipping Carboniferous strata © John Gordon.

Photo ELC_30 P3: Raised shorelines at Luffness Links Golf Course © John Gordon.

Photo ELC_30 P4: Sand dune system south of Gullane Point. © John Gordon.

Photo ELC_30 P5: Steep coastal edge south of Gullane Point. © John Gordon.

Photo ELC_30 P6: Saltmarsh and intertidal flats near the entrance to the Local Nature Reserve © John Gordon.

Photo ELC_30 P7: Intertidal flats near the entrance to the Local Nature Reserve © John Gordon.

5 Summary

A total of 30 geological sites were visited and assessed across East Lothian, and are recommended as Local Geodiversity Sites. Combined, the sites represent a wide range of geological and geomorphological features, including excellent examples of geological strata and landforms that characterise the geology and landscape of Southern Scotland as well as unique sites of international importance for geological research (Table 7). Together these sites display the geological strata, structure and features of the main geological units that crop out in East Lothian area, along with many landforms and features associated with geomorphological processes that have sculpted the landscape during Quaternary and recent times.

East Lothian has rich geodiversity and strong historic associations between its people and its landscape and resources. Many of the geodiversity sites could be enhanced to encourage visitors and students to learn more about how the geology and geomorphological processes influence the form and nature of the regions landscape.

5.1 BEDROCK EXPOSURES

In total, 21sites have been identified as local geodiversity sites for their bedrock exposures. The Lower Palaeozoic, Devonian and Carboniferous sedimentary rocks which underlie much of central and southern Scotland are well exposed in many places in East Lothian. The geodiversity sites display a wide range of features that are characteristic of these rocks, their relationships with associated extrusive and intrusive igneous rocks, and regional patterns of deformation including folding and faulting.

The oldest sedimentary strata in East Lothian are turbidite sequences from the Lower Palaeozoic, which are exposed at the north margin of the Lammermuir Hills and the southern edge of the ELC area (ELC_1) along with overlying Devonian-aged conglomerates (ELC_2). The Ballagan Formation (seen at Gin Head, ELC_3 and Dunbar, ELC_4) represents some of the oldest rocks of the Carboniferous, recording a time where the climate was wet and warm, and vegetated fluvial and coastal environments dominated the area.

In the early Carboniferous, volcanic activity caused by upwelling of magma through the crust resulted in the formation of extrusive igneous rocks including lavas and tuffs of the Garleton Hills Volcanic Formation. The volcanic rocks are exposed well at a variety of locations throughout East Lothian, but particularly along North Berwick Shore (ELC_5) and Dunbar (ELC_4) where relationships between lavas, tuffs and the sedimentary rocks can be studied. The Yellowcraig Shore (ELC_6) also provides an opportunity to study the relationship between the extrusive volcanic rocks and their relation with later intrusive igneous rocks. The resistant volcanic rocks underlie the elevated terrain and escarpments of the Garleton Hills. These rocks were historically worked for road stone from numerous small quarries across the region. The type locality of the ‘Markle Basalt’, a regionally recognised type of basalt is found within the Old Markle Quarry (ELC_7) near East Linton.

Cessation of volcanism in the East Lothian area during early to mid-Carboniferous times brought renewed deposition of sediments in a range of environments including terrestrial fluvial systems, swampy forests, deltas and shallow seas. In strata of the Gullane Formation, exposed at Gullane Point (ELC_13), and the Aberlady Formation (ELC_5 and ELC_14), sedimentary features associated with deposition in shallow marine, deltaic and fluvial settings are well preserved. Cyclic deposition of sandstone, mudstone/siltstone, limestone and later coal, occurred throughout the remainder of Carboniferous times. Key limestone horizons, formed during periods of marine inundation, are important regional stratigraphic markers in these sequences. Rare natural exposures of the Hurlet Limestone (base of the Lower Limestone Formation), and the Index Limestone (base of the Upper Limestone Formation) can be seen at Kilspindie (ELC_14) and Prestonpans Shore (ELC_15) respectively. The intervening coal-bearing Limestone Coal

Formation is also exposed at the coast at Prestonpans Shore and the shore section between Cockenzie and Port Seton (ELC_16). The youngest Carboniferous sedimentary strata seen in East Lothian belong to the Coal Measures Group, which can be seen along the coast at Cockenzie to Port Seton (ELC_16) and inland along the Esk Valley (ELC_17). Historically, the younger strata of Carboniferous age, found to the north of the Southern Upland Fault, have provided the most economically important geological resources in East Lothian; these strata have been mined and quarried for coal, limestone and sandstone for a range of usages.

Intrusion of igneous rocks in to the sedimentary strata occurred during the late Carboniferous to early Permian with the formation of numerous sills and dykes that can be seen in many of the coastal exposures, and in inland quarries such as Pencraig Quarry (ELC_18) and Kidlaw Quarry (ELC_20).

Five sites were noted for their palaeontological value, of which two are of international significance. At Cheese Bay (ELC_21) a diverse range of fossils from the early Carboniferous, including (at the time) the earliest known example of a tetrapod were historically recovered from within the Gullane Formation. However, even earlier tetrapod fossils were later found within rocks belonging to the Ballagan Formation (e.g. at Gin Head, ELC_3). These rare early tetrapod fossils are not thought to be found elsewhere in the world, and the study of the fossils and the palaeoenvironments in which the creatures lived and evolved is an area of current international research.

5.2 QUATERNARY AND RECENT DEPOSITS AND LANDFORMS

The topography across much of inland East Lothian is dominated by landforms sculpted by glacial erosion of the resistant volcanic rocks of the Garleton Hills Volcanic Formation and intrusive igneous sills, dykes and plugs. Excellent examples of glacially sculpted bedrock and related landforms occur within the Garleton Hills (ELC_22) and Whitekirk (ELC_27) sites. At Whitekirk Golf and Country Club the layout of the fairways closely follows the orientation of the ice-moulded bedrock ridges and grooves carved in the lavas. The most prominent ice-scoured feature of East Lothian is perhaps the crag and tail feature of North Berwick Law (ELC_19), a classic example of a lowland glacial landform. Roche moutonnée forms also occur in the Garleton Hills and near Kingston, south of North Berwick. Generally west of Haddington, the moulding is orientated slightly north of east, then sweeps round to slightly south of east in the eastern part of the area (Kendall & Bailey, 1908).

The lower ground is extensively mantled by a variable cover of glacial till which is well exposed in the Keith Water SSSI (Gordon & Sutherland, 1993). Erratic boulders, including metamorphic rocks of Highland origin, commonly occur along the coast and are particularly well displayed on the shore platforms where they have been washed out from the till. Good examples occur at Aberlady Bay (ELC_30), Tyninghame and Seacliff-Scoughall Shore (ELC_25). The most remarkable erratic is at Kidlaw (ELC_23), where a mass of limestone c. 0.2km^2 forms the largest known erratic in Scotland (Kendall & Bailey, 1908).

The vast quantities of meltwater produced by the melting of the last ice sheet formed distinctive assemblages of landforms, including meltwater channels cut in bedrock, and mounds, ridges and terraces of sand and gravel on the lower ground. Particularly good examples of meltwater channels occur at Rammer Cleugh SSSI (Gordon & Sutherland, 1993), around Kidlaw and between Garvald and Innerwick. Associated glacifluvial deposits, including kame terraces and ice-marginal lake deltas, occur along the northern flanks of the Lammermuir Hills from Humbie to Oldhamstocks and in the region of Tynemouth to the county boundary. Some of the best examples of glacifluvial landforms at High Latch/Longyester (Sissons, 1958) have either been removed by sand and gravel quarrying or lie within an area where there is planning consent for further extraction.

As the last ice sheet receded, relative sea-level rose and the sea invaded the lower parts of the coastline, forming raised shorelines and extended estuaries at Aberlady Bay and along the lower Tyne. Relative sea level then fell but rose again during the early Holocene before falling to its present level. These changes are represented by raised beaches and staircases of raised shorelines, for example at Gullane Shore (ELC_13), Aberlady Bay (ELC_30) and the Tyne Estuary & Belhaven Bay (ELC_28). In an embayment at Lochhouses (ELC_24), layers of marine deposits occur behind the coastal dune barrier (Newey, 1965; Robinson, 1982). One of these sand layers is attributed to a tsunami generated by a massive submarine landslide in the Storegga area off the coast of south-west Norway 8100 years ago (Smith et al., 2004). Raised, intertidal and submerged erosional shore platforms of various ages also occur along the coast at Seacliff-Scoughall Shore (ELC_26), Thorntonloch (ELC_27) and the coastal bedrock sites. Some are till covered, as at Dunbar (ELC_4), and pre-date the last glaciation.

Excellent examples of depositional coastal systems are also found in East Lothian, including the sand flats and dune systems at Gullane Bents (ELC_29), Aberlady Bay (ELC_30), and in the huge swathes of sand found in the intertidal zone within the Tyne Estuary & Belhaven Bay (ELC_28). Smaller pocket beaches and extensive areas of mudflats and saltmarshes are also found along the East Lothian coast (e.g. at Aberlady Bay and the Tyne Estuary).The varied and dynamic environments of the East Lothian coast will continue to evolve under the action of waves, wind and potentially rising sea level. This dynamism is most evident on the soft sandy reaches of the coast in the form of erosion at Gullane and the formation and dynamics of sediment bars and spits in the Tyne Estuary & Belhaven Bay and Aberlady Bay. However, it is also apparent in the breakup and weathering of shore platforms (e.g. Seacliff-Scoughall Shore (ELC_26) and Thorntonloch (ELC_27)).

Geomorphological activity has also continued inland during the Holocene. Gullying is widespread in the Lammermuir Hills, notably represented at Oldhamstocks Burn GCR site and by the development ‘badland’ topography at Burnhope (ELC_2). The postglacial rivers have also adjusted to changing discharges and sediment loads indicated by terrace formation, floodplain development, abandonment of meanders and fossil channels as along the lower River Tyne (Jackes, 1973).

5.3 GEODIVERSITY AND COMMUNITY

The form of the landscape of East Lothian, particularly the hills and coastal headlands formed of ice-moulded igneous rock, has been central to the settlement and development of the region’s towns and villages. The strong relationship between the geology and landforms, and the location of military sites and harbours can be seen at Dirleton Castle (ELC_10) and Dunbar (ELC_4).

The historic use of the area’s geological resources is also indicated at the geodiversity sites. Several of the bedrock exposures have been historically quarried for road metal (e.g. Kippielaw Quarry (ELC_9) and Craigs Quarry (ELC_11)) as well as building stone (e.g. Peppercraig Quarry (ELC_12) and North Berwick Law (ELC_19)). Coal resources from the Coal Measures Group strata to the west of the area have been important for development of local industries, and local stone has been used in the construction of many historic buildings in Dunbar, North Berwick and Haddington.

Many of the geodiversity sites are located within areas that are used for recreation and/or associated with scenic areas popular with tourists. Several also are located partially or wholly within areas that are protected for their biodiversity or ecology as Local Nature Reserves as at Aberlady Bay (ELC_30), and within the large Firth of Forth SSSI. The association of many of the geodiversity sites with the John Muir Way provides a key opportunity to develop their educational value. The addition of geological information to existing sign boards, provision of leaflets or online information, and the creation of ‘geo-trails’ would increase access to geological information about the sites for a range of potential community and educational users. Building

links between schools and their local geodiversity sites is another potential development of the educational potential of East Lothian's geodiversity.

Several of the sites have significant associations with past or current scientific research; the region has been at the forefront of research into volcanology, Carboniferous depositional environments, lowland glaciation, coastal processes and now tetrapod evolution for over a century.

5.4 LIMITATIONS AND POTENTIAL FURTHER ASSESSMENTS

The geodiversity sites identified and assessed in this study represent additional sites that complement the existing protected geological SSSIs (Table 2). However, coastal geodiversity sites lying within the large Firth of Forth SSSI have been included as these areas contain many geological features that have not been included as notified features of the SSSI. These areas are of particular importance in East Lothian and merit recognition for the quality and diversity of their geological features and landforms.

Many of the geodiversity sites are part of dynamic erosional and depositional coastal systems. In addition to natural changes in landform morphology and the extent of bedrock exposures that may arise due to ongoing erosion or deposition, the geodiversity sites may be affected by climate or sea level change. The 'soft' depositional sand flats and dune systems of coastal sites (such as Gullane Bents, Aberlady Bay and the Tyne Estuary & Belhaven Bay) are likely to be most susceptible to such changes, and these may also be at risk from intrusive land management practices. In mitigation of the risks, however, these geodivesity sites are coincident with areas that are already well protected and managed for the importance of their biodiversity and ecosystems. As far as possible, the management of these sites should aim to maintain the natural processes.

Inland quarry sites are susceptible to natural degradation through vegetation growth and weathering, but may be more at risk from waste tipping and, in some cases, development. Sandstone quarries at Gullane, reportedly the source of local stone for Dirleton Castle and other local buildings are now degrade and show no exposures. A survey of building stones and local quarry sites would help to identify, and if necessary protect, sources of local stone, providing important information relating to the preservation of local historic buildings.

The dominance of pastoral agricultural land in East Lothian is a positive aspect of the condition of inland landforms and is conducive to their long term preservation. The condition of landform features may be detrimentally affected by afforestation and development, which may obscure their morphology.

Sand and gravel extraction may also be a risk to areas of the glaciofluvial sand and gravel deposits that occur within the region. Nationally important examples of these deposits and associated meltwater channels are represented by features within the Rammer Cleugh SSSI. However, there are several other potentially regionally important examples in East Lothian which could be surveyed in future assessments. Some of the best remaining examples of glaciofluvial deposits occur at High Latch/Longyester, but these features lie within an area for which there is planning consent for further sand and gravel extraction. Depending on the final restoration conditions of the site, it may be possible to identify conservation sections in these glaciofluvial deposits at the end of working, providing an opportunity to enhance the geodiversity of the region.

Table 7: Summary of ratings for East Lothian Geodiversity sites	Site No.	Feature Type	Feature(s)	Overall Rating	
				Quality	Rarity
Gala Law	ELC_1	Bedrock exposure	Gala Group	Moderately good sedimentology and palaeontology	Local lithostratigraphy and paleontology
Burn Hope	ELC_2	Bedrock exposure	Great Conglomerate Fm	Excellent geomorphology, good lithostratigraphy and sedimentology	National geomorphology, regional lithostratigraphy
Gin Head (nr Tantallon Castle)	ELC_3	Bedrock exposure	Ballagan Fm	Excellent palaeontology	International paleontology
Dunbar Shore	ELC_4	Bedrock exposure	**Kinnesswood Fm, volcanic vents,** Ballagan Fm, Devonian rocks, **Geomorphology**	Excellent igneous geology, sedimentology and geomorphology	Regional lithostratigraphy, sedimentology, igneous geology and National Quaternary and coastal geomorphology
North Berwick Shore	ELC_5	Bedrock exposure	**Garleton Hills Volcanic Fm, volcanic vents,** Aberlady Fm	Excellent igneous geology	Regional igneous geology and lithostratigraphy
Yellow Craig Shore	ELC_6	Bedrock exposure	**Garleton Hills Volcanic Fm,** volcanic vents, Gullane Fm	Excellent lithostratigraphy and igneous geology	Regional lithostratigraphy and igneous geology
Old Markle Quarry	ELC_7	Bedrock exposure	Garleton Hills Volcanic Fm	Good igneous geology	Regional igneous geology
Blaikie Heugh – Balfour Monument	ELC_8	Bedrock exposure	Garleton Hills Volcanic Fm	Moderately good igneous geology	Regional/national igneous geology
Kippielaw Quarry	ELC_9	Bedrock exposure	Garleton Hills Volcanic Fm	Poor igneous geology	Local igneous geology
Dirleton Castle	ELC_10	Bedrock exposure	Garleton Hills Volcanic Fm	Excellent igneous geology	Local igneous geology
Craigs Quarry	ELC_11	Bedrock exposure	Garleton Hills Volcanic Fm	Moderately good igneous geology	Local igneous geology
Peppercraig Quarry	ELC_12	Bedrock exposure	Garleton Hills Volcanic Fm	Poor igneous geology	Local igneous geology
Gullane Shore	ELC_13	Bedrock exposure	**Gullane Fm,** igneous sills, Quaternary landforms	Excellent sedimentology	Regional lithostratigraphy
Kilspindie	ELC_14	Bedrock exposure	**Lower Limestone Fm,** Aberlady Fm, igneous sill	Excellent paleontology	Regional paleontology and lithostratigraphy
Prestonpans Shore	ELC_15	Bedrock exposure	Upper Limestone Fm, Limestone Coal Fm	Excellent lithostratigraphy	Regional lithostratigraphy and paleontology
Continued on next page					

Table 7: Summary of ratings for East Lothian Geodiversity sites (continued)	Site No.	Feature Type	Feature(s)	Overall Rating	
				Quality	Rarity
Cockenzie – Port Seton Shore	ELC_16	Bedrock exposure	**Lower Coal Measures, Passage Fm, Upper Limestone Fm**	Excellent lithostratigraphy	Regional lithostratigraphy
Esk Valley	ELC_17	Bedrock exposure	**Middle Coal Measures**	Excellent lithostratigraphy	Regional lithostratigraphy
Pencraig Wood Quarry	ELC_18	Bedrock exposure	**Igneous sill, geomorphology**	Good geomorphology, poor igneous geology	Local geomorphology and igneous geology
North Berwick Law	ELC_19	Bedrock exposure	**Geomorphology,** volcanic vent	Good geomorphology, good igneous geology	Regional geomorphology and igneous geology
Kidlaw Quarry	ELC_20	Bedrock exposure	**Volcanic plug**	Good igneous geology	Regional/national igneous geology
Cheese Bay	ELC_21	Bedrock exposure	**Palaeontology,** Gullane Fm	Excellent palaeontology	International paleontology
Garleton Hills	ELC_22	Landform/Quaternary	**Ice moulded bedrock**	Excellent geomorphology	Regional geomorphology
Kidlaw Erratic	ELC_23	Landform/Quaternary	**Glacial erratic**	Excellent geomorphology	Regional/national geomorphology
Lochhouses	ELC_24	Landform/Quaternary	**Tsunami deposit**	Good geomorphology	Regional geomorphology
Seacliff – Scoughall Shore	ELC_25	Landform/Quaternary	**Shore platform**	Excellent geomorphology	Regional/national geomorphology
Thorntonloch	ELC_26	Landform/Quaternary	**Coastal landforms**	Good/excellent geomorphology	Regional geomorphology
Whitekirk	ELC_27	Landform/Quaternary	**Glacial erosion**	Good geomorphology	Regional geomorphology
Tyne Estuary & Belhaven Bay	ELC_28	Landform/Quaternary	**Geomorphology**	Excellent geomorphology	Regional geomorphology
Gullane Bents	ELC_29	Landform/Quaternary	**Sand dune restoration**	Good/excellent geomorphology	Regional geomorphology
Aberlady Bay	ELC_30	Landform/Quaternary	**Coastal landforms**	Good/excellent geomorphology	Regional geomorphology

Table 7: Summary of ratings for East Lothian Geodiversity sites (note 'Fm' is an abbreviation of Formation). Under 'Feature(s)' column, the feature of most interest is presented in bold text.

Table 8: Geological Features Visible at Geodiversity Sites	Site No.	Lower Palaeozoic strata	Devonian strata	Kinnesswood Formation	Ballagan Formation	Garleton Hills Volcanic Formation	Gullane Formation	Aberlady Formation	Lower Limestone Formation	Limestone Coal Formation	Upper Limestone Formation	Passage Formation	Coal Measures	Early Carboniferous Volcanic Plugs and Vents	Carboniferous to Early Permian Sills	Carboniferous to Early Permian Dykes	Geological Structures	Fossils and Paleontology	Geomorphology	Quaternary Deposits/Feature	Economic Heritage	Built Heritage
Gala Law	ELC_1	●															●	●				
Burn Hope	ELC_2		●													●			●			
Gin Head (nr Tantallon Castle)	ELC_3				●												●	●				
Dunbar Shore	ELC_4		●	●	●									●		●	●		●	●	●	●
North Berwick Shore	ELC_5					●		●						●			●		●	●		●
Yellow Craig Shore	ELC_6					●	●							●	●		●					
Old Markle Quarry	ELC_7					●															●	
Blaikie Heugh – Balfour Monument	ELC_8					●																
Kippielaw Quarry	ELC_9					●															●	
Dirleton Castle	ELC_10					●																●
Craigs Quarry	ELC_11					●															●	

Table 8: Geological Features Visible at Geodiversity Sites (continued)	Site No.	Lower Palaeozoic	Devonian strata	Kinnesswood Formation	Ballagan Formation	Garleton Hills Volcanic Formation	Gullane Formation	Aberlady Formation	Lower Limestone Formation	Limestone Coal Formation	Upper Limestone Formation	Passage Formation	Coal Measures	Early Carboniferous Volcanic Plugs and Vents	Carboniferous to Early Permian Sills	Carboniferous to Early Permian Dykes	Geological Structures	Fossils and Paleontology	Geomorphology	Quaternary Deposits/Feature	Economic Heritage	Built Heritage
Peppercraig Quarry	ELC_12					●															●	●
Gullane Shore	ELC_13						●								●					●		●
Kilspindie	ELC_14							●	●						●			●	●			
Prestonpans Shore	ELC_15									●	●					●	●	●			●	●
Cockenzie – Port Seton Shore	ELC_16										●	●	●									
Esk Valley	ELC_17												●									
Pencraig Wood Quarry	ELC_18														●						●	
North Berwick Law	ELC_19					●													●		●	●
Kidlaw Quarry	ELC_20													●							●	
Cheese Bay	ELC_21						●											●				
Garleton Hills	ELC_22																		●	●		
Kidlaw Erratic	ELC_23																		●	●		
Lochhouses	ELC_24																		●	●		

Table 8: Geological Features Visible at Geodiversity Sites (continued)	Site No.	Lower Palaeozoic	Devonian strata	Kinnesswood Formation	Ballagan Formation	Garleton Hills Volcanic Formation	Gullane Formation	Aberlady Formation	Lower Limestone Formation	Limestone Coal Formation	Upper Limestone Formation	Passage Formation	Coal Mesures	Early Carboniferous Volcanic Plugs and Vents	Carboniferous to Early Permian Sills	Carboniferous to Early Permian Dykes	Geological Structures	Fossils and Palaeontology	Geomorphology	Quaternary Deposits/Feature	Economic Heritage	Built Heritage
Seacliff – Scoughall Shore	ELC_25																		●	●		
Thorntonloch	ELC_26																		●	●		
Whitekirk	ELC_27																		●	●		
Tyne Estuary	ELC_28																		●	●		
Gullane Bents	ELC_29																		●	●		
Aberlady Bay	ELC_30																		●	●		

Table 8: Geological features present at the Geodiversity Sites.

Appendix 1 Geological Conservation Review Sites

No.	Site Name	Site Code	Block of GCR	National Grid Reference	SSSI or ELC_GeoDiversity Site Reference
1	Bangley Quarry	2428	Mineralogy of Scotland	NT 488751	SSSI (geol)
2	Barns Ness Coast	1556	Dinantian of Scotland	NT 697782	SSSI (geol)
3	Cheese Bay	2916	Carboniferous - Permian Fish/Amphibia	NT 492856	ELC_21
4	Dunbar	2301	Coastal Geomorphology of Scotland	NT 670794	ELC_4
5	Dunbar	182	Quaternary of Scotland	NT 661788	ELC_4
6	Garleton Hills	1155	Carboniferous - Permian Igneous	NT 510765	ELC_22
7	Keith Water	748	Quaternary of Scotland	NT 440621	SSSI (geol/bio)
8	North Berwick Coast	1375	Carboniferous - Permian Igneous	NT 496858	ELC_5
9	Oldhamstocks Gullies	2209	Fluvial Geomorphology of Scotland	NT 710690	SSSI (geol/bio)
10	Oxroad Bay	365	Palaeozoic Palaeobotany	NT 599848	SSSI (geol)
11	Rammer Cleugh	712	Quaternary of Scotland	NT 640720	SSSI (geol)
12	Traprain Law	1376	Carboniferous - Permian Igneous	NT 581746	SSSI (geol/bio)
13	Weak Law	857	Palaeozoic Palaeobotany	NT 499858	

Table 9: Geological Conservation Review sites (GCR) in East Lothian

The Geological Conservation Review was designed to identify sites of national and international importance needed to show all the key scientific elements of the Earth heritage of Britain. It includes over 3000 GCR sites, selected from around 100 categories (the GCR 'Blocks') and are published in a series of 45 volumes. Developed by the Joint Nature Conservation Committee (JNCC).

Appendix 2 Lothian and Borders GeoConservation Publications

No.	Site Name	Leaflet Style	Designated 'Local Geodiversity Site'	SSSI, GCR or ELC_Geodiversity Site Reference
1	Barns Ness	Basic and Full versions available.	Yes, 2002	SSSI (geol)
2	Belhaven Bay	Basic version currently available.	No	ELC_28
3	Dunbar Harbour	Basic version currently available. Full version in prep.	No	ELC_4
4	North Berwick	Basic and Full versions available.	Yes, 2005	ELC_5
5	Traprain Law	Basic version currently available.	Yes, 2006	SSSI (geol/bio)

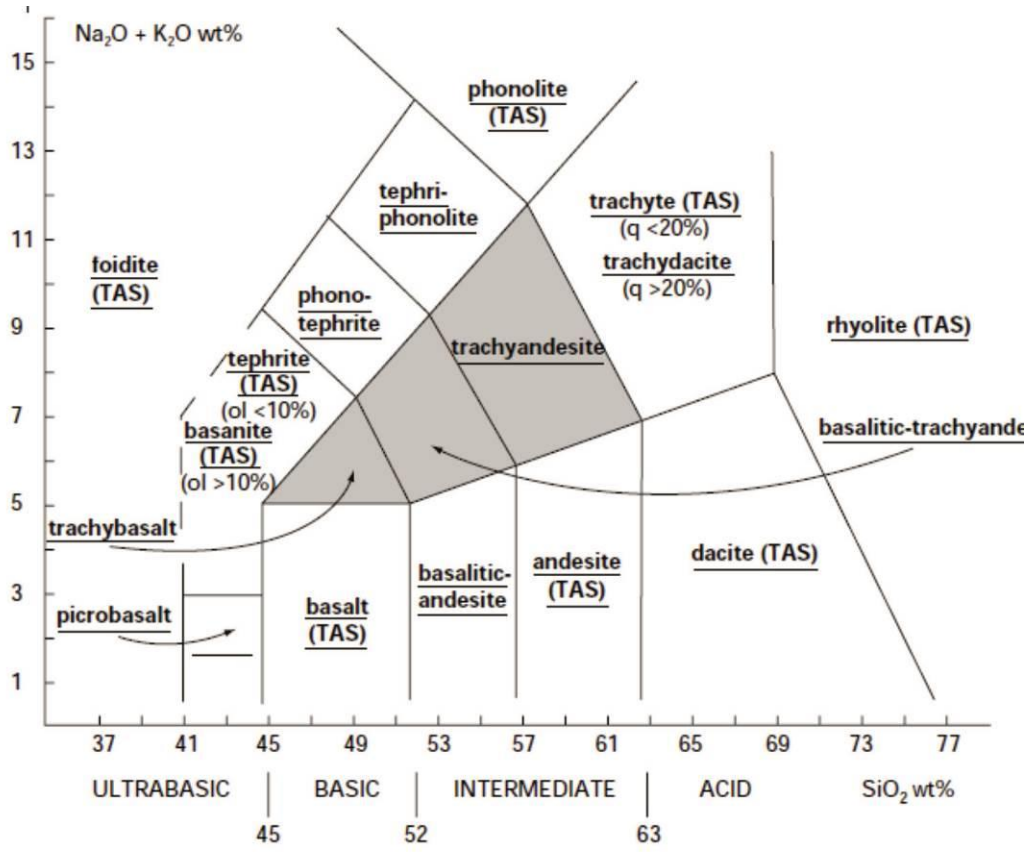
Table 10: Sites already designated as a 'Local Geodiversity Site' and/or have existing geological leaflets.

Full= leaflets completed by Lothian and Borders GeoConservation group (formerly RIGS), describing the geology of the area

Basic= in 2001, Lothian and Borders RIGS (Regionally Important Geological and Geomorphological Sites) joined in partnership with Girlguiding East Lothian to introduce a geology theme to their programme. Over the next few years, four colourful leaflets were produced.

Dates of designation, were found on the Edinburgh Geological Society Website (under GeoConservation)

Appendix 3 Chemical classification and nomenclature of fine-grained crystalline rocks



Further subdivisions of shaded fields	trachybasalt	basaltic-trachyandesite	trachyandesite
$Na_2O - 2.0 \geq K_2O$	hawaiite	mugearite	benmoreite
$Na_2O - 2.0 \leq K_2O$	potassic-trachybasalt	shoshonite	latite (TAS)

Total alkali silica (TAS) diagram (sourced from BGS Rock Classification Scheme, Volume 1, Classification of igneous rocks). The scheme names igneous crystalline rocks based on their silica to sodium/potassium content.

Appendix 4 Additional site audit for the Forth Islands

ELC_31: Forth Islands

Site Information

Location and Summary Description:

The Forth Islands comprise a series of small, uninhabited islands, in the Firth of Forth and fall within the East Lothian District. The islands lie between 350 m and 2 km from the mainland and comprise, from west to east, Eyebroughy, Fidra, Lamb, Craigleith and Bass Rock.

The islet of Eyebroughy is connected to the mainland at low tide and is included within site ELC_6 of the East Lothian Geodiversity Audit. An expanded description of the geology of Eyebroughy is included within this assessment; the site boundary can be seen in Figure 11. For the remaining islands, site boundaries are shown in Figures 36 to 39.

National Grid Reference: Eyebroughy: [349431, 686263] Fidra: [351264, 686840] Lamb: [353474, 686603] Craigleith: [355282, 687001] Bass Rock: [360220, 687391]	**Site type**: • Natural exposure • Natural view
Site ownership: varied	Current use: Varied
Field surveyors: n/a	Current geological designations: Eyebroughy - SSSI (mixed geological/biological)
Date visited: n/a	Other designations: SSSI (biological), SPA, RSPB reserve

Site Maps

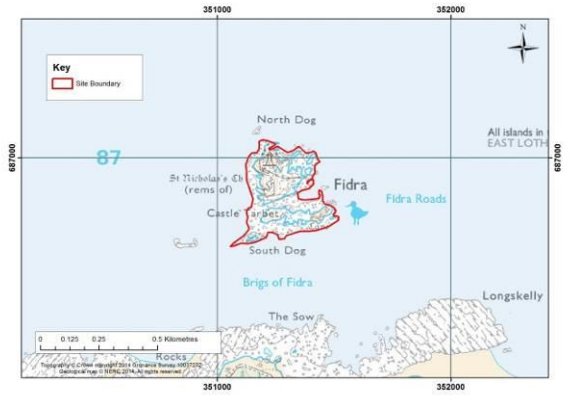


Figure 36: Fidra Location Map. Site boundary is drawn to include rock exposures to mean low water spring level.

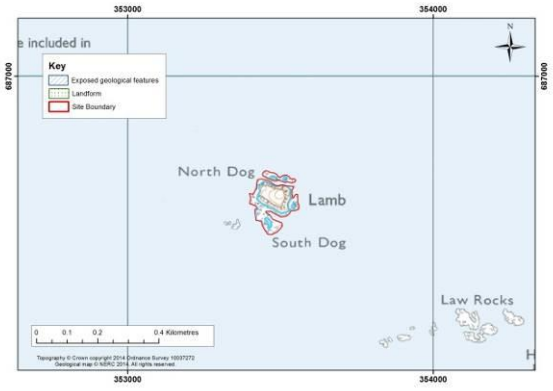


Figure 37: Lamb Location Map. Site boundary is drawn to include rock exposures to mean low water spring level.

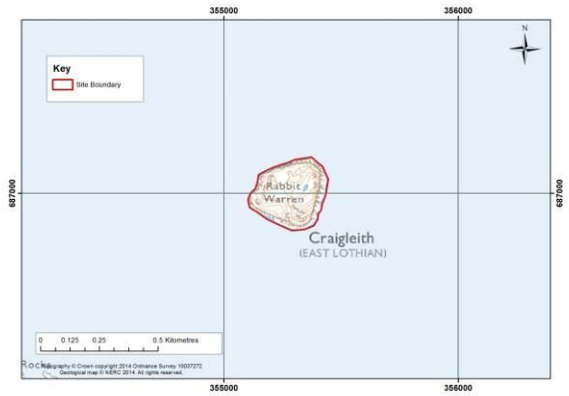


Figure 38: Craigleith Location Map. Site boundary is drawn to include rock exposures to mean low water spring level.

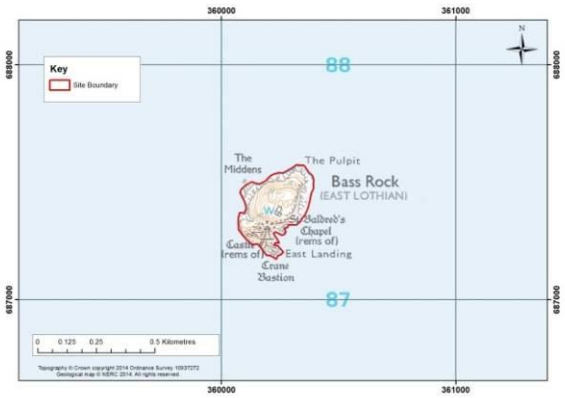


Figure 39: Bass Rock Location Map. Site boundary is drawn to include rock exposures to mean low water spring level.

Site Description

Background

The Forth Islands are a Special Protection Area (SPA), supporting the main seabird colonies in the Firth of Forth (auks, gulls and gannets in particular). All of the islands are also designated as SSSIs. Eyebroughy falls under the Firth of Forth SSSI designation (geological and biological), Fidra, Lamb and Craigleith fall under the Forth Islands SSSI (biological: birds) and Bass Rock has SSSI (biological) status for its breeding colonies of the Northern gannet and other seabirds. All of the islands are composed of Lower Carboniferous aged volcanic intrusions. The following descriptions are based on a desktop review of historic geological maps, BGS memoirs, and published literature.

Eyebroughy (see ELC_6 for site boundary)

Igneous Rocks

The small island of Eyebroughy consists entirely of a non-porphyritic quartz-trachyte intrusion. The contacts with the surrounding country rock are not exposed. The intrusion (interpreted as a sill) contains north-north-east trending fractures throughout, giving the rock exposures a flaggy platiness in appearance. In the intertidal zone between Eyebroughy and the mainland is a poorly exposed area of yellow breccia with large blocks of fine-grained igneous rocks, interpreted as a volcanic vent.

Access and Additional Information

Eyebroughy forms part of the recommended local geodiversity site ELC_6 within the East Lothian Geodiversity Audit. The island is accessible by foot at low tide, and the interior of the island remains exposed at high tide. The island, noted for its cormorants, is also a RSPB reserve and therefore access may be restricted.

Fidra

Igneous Rocks

The island of Fidra is entirely composed of an intrusive sill of fine-grained olivine-basalt, and is believed to be part of the same sill as that on Lamb. Vertical columnar joints cut by near-horizontal joint planes are common, and nodules of peridotite and pyroxenite have also been found, along with xenoliths of sedimentary rocks. No contacts with the surrounding country rocks are visible. Geological field slips show one or two faults cutting the sill.

Quaternary Deposits and Landforms

Fidra has a 30 – 40 ft. high natural rock arch on its north-eastern side and a cave on its south-eastern side, both formed as a result of coastal erosion. Fidra also has a raised shore platform, formed during relative sea-level rise following retreat of the Late Devensian age glacier in the Firth of Forth. This raised shore platform was then abandoned during Holocene times due to the relative sea level fall which resulted from isostatic rebound of the land surface following unloading of the ice sheet.

Access and Additional Information

The island is accessible by boat, with a small jetty on the east of the island. The cliffs on Fidra provide good exposures, although the natural joints offer excellent nesting sites for the seabirds, and as such, access may be restricted. The island, noted for its puffins, guillemots, razorbills and shags, is also a RSPB reserve. Although the interior of the island has extensive thin soil and grass cover, exposures of the bed rock may be accessible without interfering with the sea birds.

Lamb

Igneous Rocks

Lamb, and its two flanking islands North Dog and South Dog, are entirely composed of intrusive fine-

grained olivine-basalt, and are believed to be part of the same sill as Fidra. Vertical columnar joints around 30 to 50 cm in diameter are common and better developed than on Fidra. The columns are inclined to the east-south-east at an angle of 80°, in the west, to 45° in the east. No contacts with the surrounding country rocks are visible. Geological field slips show a fissure and belt of breccia up to 2 feet wide with anastomosing veinlets at the south-west of the island.

Access and Additional Information

Lamb is only accessible by boat, although there are no landing facilities. Due to sea birds inhabiting the island access may be restricted. The interior of the island has a partial cover of thin soil and grass above the mean high water mark.

Craigleith

Igneous Rocks

Craigleith is entirely formed of a laccolith of fine-grained, non-porphyritic trachybasalt, or fine-grained essexite (Clough et al., 1920). A laccolith is a domed body of igneous rock intruded roughly horizontally between intervening rock layers, giving the intrusion a 'blister' shape. Contacts with surrounding rocks are not seen. The laccolithic form is suggested by the orientations of the prominent joint system on the island; the present shape of the island is thought to be similar to that of the original intrusion. Clough et al., (1920) note similarities in the petrology of the trachybasalt at Craigleith to that of the Kidlaw basanite seen at site ELC_20 of the East Lothian Geodiversity Audit.

Access and Additional Information

Craigleith is only accessible by boat, and makes a popular day boat trip from North Berwick to see the birdlife (namely puffins). Like the other Forth Islands, due to sea birds and seals inhabiting the island, access may be restricted. Joint planes in the trachybasalt can be clearly seen whilst on a boat trip around the island. The interior of the island is largely covered by thin soil and grass, with sparse rock exposure.

Bass Rock

Igneous Rocks

At 107 m in height, Bass Rock is the largest of the Forth Islands within the East Lothian district. This iconic landmark is a classic volcanic plug composed of non-porphyritic, fairly coarse-grained phonolitic trachyte. Its vertical cliffs reflect the edge of the hard resistant plug, and it is massively jointed. Geological field slips show some of the joints are slickenlined, and there are crush zones marked (fault zones). Bass Rock is composed of the same rock type as North Berwick Law (see ELC_19 in the East Lothian Geodiversity Audit), and both represent the eroded remnants of two individual volcanoes which were active during Carboniferous times. The volcanic plugs formed when the volcanic activity ceased, and the molten rock within the pipe feeding the volcanoes cooled.

Access and Additional Information

Bass Rock supports the largest single-rock northern gannet colony in the world, with over 48,000 pairs recorded in 2004. Regular boat trips around the island run from North Berwick, with some offering landings on the island. However, access to much of the island is likely to be restricted through the nesting and breeding season due to the sheer numbers of gannets and other sea birds. The boat trip around the island affords good views toward the margin of the volcanic plug along vertical joint planes. The remains of a castle and chapel can be found above the cliffs on the south-side of Bass Rock.

Stratigraphy and Rock Types	
Age: Carboniferous	Formation: Midland Valley Early Carboniferous Felsic Sill Suite
Rock type: Trachyte (Eyebroughy Sill)	
Age: Carboniferous	Formation: Midland Valley Carboniferous to Early Permian Alkaline Basic Sill Suite
Rock type: Basalt, olivine-macrophyric (Fidra Sill)	
Age: Carboniferous	Formation: Midland Valley Carboniferous to Early Permian Alkaline Basic Sill Suite
Rock type: Basalt, olivine-macrophyric (Lamb Sill)	
Age: Carboniferous	Formation: Midland Valley Carboniferous to Early Permian Alkaline Basic Sill Suite
Rock type: Trachybasalt (Craigleith Sill)	
Age: Carboniferous	Formation: Southern Scotland Dinantian Plugs and Vents Suite
Rock type: Phonolite (Bass Rock Plug)	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	n/a
Safety of access	The islands, aside from Eyebroughy, are only accessible by boat. Eyebroughy can be accessed by foot at low tide, and any visitors should be aware of tide times.
Safety of exposure	Most of the rock exposures are on coastal cliffs, often inhabited by sea birds. Local rock exposures in the interiors of the islands may be more accessible where landing by boat is possible. Stout footwear and warm waterproof clothing is recommended.
Current condition	The sites were not observed in the field for this assessment. However, the remote location and continual erosion of the cliffs by wave action means that rock exposures are considered likely to be in good condition.
Current conflicting activities	Sea bird nesting/breeding/residency; boat tours.
Restricting conditions	Sea condition; tide
Nature of exposure	Intertidal and cliff exposures, some open inland rock exposure.

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	Robert Louis Stevenson took inspiration for his book ‘Catriona’ from the nearby islands of Fidra and Lamb, and many people believe Fidra was the inspiration for his ‘Treasure Island’. There remain the ruins of castles and chapels on Fidra and Bass Rock.
Aesthetic landscape	Coastal
History of Earth Sciences	Petrology
Economic geology	No known association

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Litho Stratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology	National	Good	McAdam and Tulloch (1985), Davies et al., (1986)	X
Structural Geology				
Palaeontology				
Geomorphology	Local	Good		

Site Geoscientific Value

Combined, the Forth Islands of East Lothian comprise a sequence of intrusive volcanic rocks (plug, laccolith and sills), representative of the internal plumbing of volcanic activity that dominated the area during the Carboniferous. The phonolitic trachyte of Bass Rock is only found in one other location in the UK (at the neighbouring North Berwick Law) and as such is of national significance. The trachyte, basalt and trachybasalt comprising Eyebroughy, Fidra, Lamb and Craigleith are found elsewhere in Carboniferous volcanic rocks in Scotland and are therefore of local significance. Bass Rock is an excellent example of a volcanic plug, although restrictions in access and exposure due to bird life lower the designation here from excellent to good quality.

The natural rock arch and raised shoreline on Fidra provide a good quality, local example of coastal erosion processes. As the islands are composed of hard crystalline volcanic rock, they stand proud and are more resistive to erosion than the surrounding sedimentary rocks. As an onshore example, North Berwick Law (composed of the same hard phonolitic trachyte as Bass Rock) stands proud of the surrounding landscape, which is composed of softer Carboniferous sedimentary rocks. North Berwick Law forms a crag and tail structure due to differential glacial erosion (see ELC_19 in the East Lothian Geodiversity audit) – it is possible the volcanic plug and laccolith of Bass Rock and Craigleith also have submerged crag and tails as a result of glacial erosion. Coastal erosion from wave action continuously erodes the base of the cliffs of the islands, giving rise to their steep-sided morphology.

In combination, The Forth Islands provide a good example of an intrusive Carboniferous sequence, with national significance, along with a good example of coastal erosional processes with local significance.

Assessment of Site: Current site usage

Community	Local boat trips to see the sea birds run from North Berwick to Bass Rock and Craigleith during tourist season. The Scottish Seabird Centre provides a significant tourist attraction.
Education	The islands are not easily accessible for field visits. However, the forms of the Craigleith laccolith and the volcanic plug of Bass Rock are better appreciated from the coast and could be included in a geological guide to the area.

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering/erosion
Potential use	Leaflets, interpretation boards onshore linked in with other recommended local geodiversity sites in the East Lothian Area. Incorporation of geodiversity in the Scottish Seabird Centre (describing the geology that makes these islands prime sites for bird breeding colonies).

Geodiversity Summary

The Forth Islands of East Lothian expose a range of intrusive Carboniferous volcanic rocks, from sills, to laccoliths to volcanic plugs. Viewed from the shore, Craigleith and Bass Rock maintain more or less their original subsurface geometries, allowing a snapshot of the internal plumbing of a volcanic system to be visualised. Fidra also has a good example of a natural rock arch and raised shoreline, allowing an appreciation of coastal erosional processes and sea level change over time. The intrusive volcanic rocks are visible today as the Forth Islands due to their erosion resistant nature, and as such they stand proud from the softer (and therefore more eroded) sedimentary rocks. Coastal erosion continues to actively erode the bases of the cliffs. Access is difficult to the islands themselves and therefore interpretation boards on the coast line looking out toward the islands would provide visitors with relevant geological information.

Site Photos

Photo ELC_31 P1: Joint surfaces are exposed in the trachybasalt on Craigleith. The orientation of the joints on the island indicates that the shape of the island is largely that of the original intrusion – the “blister-shaped” intrusion is known as a laccolith. © BGS, NERC.

Photo ELC_31 P2: The coastal exposures on Craigleith are controlled by the orientation of the joints that cut the trachybasalt – these joints make ideal nesting locations for local sea birds. © BGS, NERC.

Photo ELC_31 P3: The striking Bass Rock is the remnants of a volcanic plug, highly resistant to erosion due to its strength. © BGS, NERC.

Photo ELC_31 P4: The cliffs of Bass Rock are formed sub-parallel to the dominant joint trend in places, providing good nesting locations for local sea birds. © BGS, NERC.

Glossary

'aa' flow	Rapid flowing lava which when cool exhibits a rough, clinkery surface.
Anlacime	A white, pink or grey aluminosilicate mineral containing sodium associated with basic igneous rocks.
Alluvial	Environments, actions and products of rivers or streams.
Amygdale	Vesicles and cavities in lavas which are infilled with minerals.
Anticline	A structural term describing an arch-shaped fold in rock in which the rock layers are upwardly convex. The oldest rock layers form the core of the fold, and outward from the core progressively younger rocks occur.
Augite	A silicate mineral, the most common pyroxene, dark green to black in colour.
Basalt	A fine-grained, dark-coloured igneous rock composed of iron and magnesium rich minerals.
Basanite	A fine-grained extrusive igneous (volcanic) rock of basic to ultra-basic composition (relatively low in silica and alkali content; see Appendix 3)
Bedding	A feature of sedimentary rocks, in which planar or near-planar surfaces known as bedding planes indicate successive depositional surfaces formed as the sediments were laid down.
Bedrock	A term used to describe unweathered rock below soil or superficial deposits. Can also be exposed at the surface.
Biotite	A common aluminosilicate mineral commonly forming brown crystals with a characteristic platy cleavage.
Bioturbation	The disruption of depositional sedimentary structures by organisms e.g. activities such as burrowing.
Bivalve	Class of molluscs with paired oval or elongated shell valves joined by a hinge (e.g. mussels).
Brachiopods	A phylum of solitary marine shelled invertebrates, the shell is made up of two unequal valves.
Breccia	A coarse-grained clastic rock, composed of angular rock fragments. Breccias are formed in sedimentary and volcanic environments, and via tectonic processes.
Calcite	Calcium Carbonate [$CaCO_3$] a widely distributed mineral and a common constituent of sedimentary rocks, limestone in particular. Also occurs as stalactites and stalagmites and is often the primary constituent of marine shells.
Calcareous	Containing calcium carbonate.
Carboniferous	A geological period [359–299 Ma] of the Palaeozoic Era preceded by the Devonian and followed by the Permian.
Cementstone	A name used to describe a limestone, usually containing clays, that is, or was, used to make cement.
Clast	Particle of broken down rock, eroded and deposited in a new setting.
Clinopyroxene	Common aluminosilicate mineral usually forming black or green crystals.
Columnar jointing	A type of jointing which looks like columns. Found in igneous rocks and results from the internal contraction during cooling of lava, as seen in the vertical columns of the Giant's Causeway, N. Ireland.
Conglomerate	A coarse-grained clastic sedimentary rock, a significant proportion of which is

	composed of rounded or subrounded pebbles and boulders.
Country rock	A general term used to describe any rock which has been penetrated by an igneous intrusion.
Crinoid	A sea dwelling creature (class Crinodea) which has survived since Ordovician times. They are known as sea-lilies and have three sections, the stem, the calyx and feather-like arms by which they collect food. There abundance in the Palaeozoic era has meant that their remains have formed large thicknesses of limestone due to their calcareous skeletons.
Cross-bedding	Sets of strata which are inclined to the general stratification of the beds. They dip in the direction of fluid flow at the time when the beds were laid down.
Desiccation cracks	Polygonal cracks formed in a sediment as it dries out in a terrestrial environment, also known as shrinkage cracks
Devensian	The last glacial stage in Britain, lasting from around 116 000 BP (Before Present) to about 11,700 BP.
Devonian	A geological period [416–359 Ma] of the Palaeozoic Era preceded by the Silurian and followed by the Carboniferous.
Dolomitic limestone	A limestone containing a high concentration of the mineral dolomite
Dyke	A sheet-like body of intrusive igneous rock emplaced along a vertical or near vertical fracture, normally discordant to the structure in the country rocks.
Dune slack	The flat areas that lie between the ridges of a coastal dune system. The area is usually covered in vegetation as it lies close to the water table.
Earth heritage	The geological and landscape heritage of an area. Used mostly in the context of geoconservation.
Earth science	Science related to planet Earth. Also known as geoscience. Includes disciplines such as economic geology, geochemistry, geomagnetism, geomorphology, geophysics, glaciology, hydrogeology, mineralogy, palaeontology, petroleum geology, petrology, stratigraphy, structural geology, engineering geology, sedimentology, seismology.
Erratic	A piece of rock (can vary in size from pebbles to very large boulders) which has been transported by glacial ice often over a large distance.
Esker	A long and winding landform composed of stratified sand and gravel formed by streams flowing beneath or on a glacier.
Extrusive	Describes igneous rocks that have been extruded onto the Earth's surface, rather than being intruded beneath the surface (intrusive).
Fault	A fracture in the Earth's crust across which the rocks have been displaced relative to each other.
Fault plane	A vertical or dipping surface of a fault.
Feldspar	A group of common aluminosilicate minerals, typically forming white or light pink crystals.
Fissile	A term used to describe a rock which is easily split.
Fluvial	Referring to a river environment**.**
Fold	A bend in planar structures such as rock strata or bedding planes.
Formation	The fundamental unit used in lithostratigraphy. Specific features distinguish one formation from another. Formations may be subdivided into members and several formations may constitute a group.

Gastropod	Molluscs belonging to the class Gastropoda, usually with coiled shells.
Geomorphology	The study of landforms and the processes that form them
Glaciofluvial	Refers to sediments deposited by flowing glacial meltwater.
Graptolites	A class of extinct colonial animals that lived from the Cambrian (542Ma to 488Ma) through to the early Carboniferous. They were marine in origin and are often found preserved in mudstones and shales deposited in deep water environments.
Hematite	Iron oxide (FeO_2)
Holocene	The youngest epoch of the Quaternary Sub-Era. Covers the last 11 800 years. The concept of the Holocene ending at the end of the 18th Century is gaining ground, with the following Epoch termed the Anthropocene.
Hornblende	A common aluminosilicate mineral commonly forming green or brown crystals.
Igneous rocks	A rock that has formed from the cooling of magma (molten rock).
Intrusion	A body of igneous rock which has been injected as magma into existing hard rocks (country-rock). On cooling the magma is called an igneous intrustion.
Joints	A fracture, or potential fracture, in a rock adjacent to which there has been no displacement.
Ka	Abbreviation for kiloannus meaning a thousand years
Kame terrace	A terrace between a hillside and a glacier formed by glaciofluvial activity.
Lacustrine	Refers to a lake environment.
Limestone	Sedimentary rock composed mainly of calcium carbonate.
Lithology	The character of a rock expressed in terms of its mineral composition, structure, grain size and arrangement of its constituents.
Lithostratigraphy	The branch of stratigraphy concerned with the description of rock units in terms of their lithological features and spatial relationships
Ma	Abbreviation for megannum (or more correctly, megannus) meaning million years
Macrophyric	A textural term describing a coarse-grained crystalline igneous rock
Mafic	Term referring to a dark coloured igneous rock
Magma	Molten rock.
Marl	A sedimentary rock, a calcareous (lime-rich) mudstone, or clay-rich chalk.
Massive	A term used to describe a thick rock unit without any stratification, jointing or fracturing.
Meltwater	Water produced by melting of snow or ice.
Microporphyritic	A fine grained igneous rock containing pheoncrysts less than 0.025 mm in diameter.
Mugearite	A fine-grained extrusive igneous rock (volcanic) of intermediate composition. Mugearite is a subdivision of basaltic-trachyandesite with a high Sodium (Na) content (see Appendix 3).
Nepheline	A feldspathoid mineral high in alkali (K and Na) but low in silica found in igneous rocks. Typically white in colour and hard to identify.
Olivine	A common aluminosilicate mineral forming near-spherical greenish crystals (phenocrysts) in many igneous rocks.
Ordovician	A geological period [495–443 Ma] of the Palaeozoic Era preceded by the

	Cambrian and followed by the Silurian.
Ostracod	Small aquatic crustacean dating back to Cambrian times, [class: Ostracoda]. Ostracods vary in size from 0.2mm to 30mm and have a bivalve-like protective shell. They are very important in correlating palaeoenvironments due to their worldwide occurrence.
Palaeozoic	The lowest era of the Phanerozoic Eon. It is preceded by the Proterozoic and is followed by the Mesozoic, [542–251Ma].
Periglacial	Conditions, processes and landforms associated with cold, nonglacial environments.
Permian	A geological period [299–251 Ma] of the Palaeozoic Era preceded by the Carboniferous and followed by the Triassic.
Phenocryst	Large crystals, usually of near perfect shape, which occur in a finer-grained groundmass in igneous rocks.
Phonolite	A fine-grained extrusive igneous rock (volcanic) of intermediate composition with very high alkali content (K + Na; see Appendix 3).
Phreatomagmatic	Pertaining to a volcanic explosion that extrudes both magmatic gases and steam, occurring when magma is in contact with water either groundwater or sea water.
Plagioclase	A common feldspar mineral forming elongate white crystals
Porphyritic	The term applied to igneous rocks which contain isolated crystals, or phenocrysts, larger than those forming the main body of the rock.
Pseudomorph	A secondary mineral which has replaced another but maintained its shape.
Pyroxene	A common aluminosilicate mineral forming black or dark brown crystals in igneous rocks.
Quartz	The mineral form of silicon dioxide (SiO_2). The most abundant and widespread of all minerals, it generally appears transparent or white and is hard enough to scratch glass.
Quartz-microgabbro	Medium grained basic igneous rock containing minor quartz.
Quaternary	A geological sub-era [2.6 Ma to present day] of the Cenozoic Era, following the Neogene.
Reduction spots	A typically spherical feature found in reddened rocks, where its colour has been bleached by local chemical reduction of the iron compound to its ferrous state. This reduction is typically white or pale-green, and also forms as linear features along fractures.
Rinnenkarren	Solution grooves that form due to channelization of runoff in calcareous rock surfaces.
Ripple marks	Small scale ridges and troughs formed by the flow of water or wind over unconsolidated sandy or silty sediment. The fossilised equivalent of ripples found today on beaches and river sands.
Roche moutonée	A feature formed by glacial erosion, usually a mound of rock with one side moulded by the ice and the other side steepened.
Runnel	A very small stream
Seat earth	A sedimentary rock underlying a coal seam representing an old soil that supported the vegetation from which the coal has formed.
Sedimentary rock	A rock formed in one of three main ways: by the deposition of the weathered remains of other rocks (clastic sedimentary rock); by the deposition of the results of biogenic activity; and by precipitation from solution. Four basic processes are involved in the formation of a clastic sedimentary rock: weathering (erosion),

	transportation, deposition and compaction.
Sill	A tabular igneous intrusion with concordant contacts with the surrounding country rocks
Silurian	A geological period [443–417 Ma] of the Palaeozoic Era preceded by the Ordovician and followed by the Devonian.
Slickensides	A polished rock surface, usually displaying linear grooves and ridges (slickenlines). Found on fault planes and caused by the movement of adjacent blocks of rock.
Spheroidal weathering	A type of chemical weathering where jointed blocks of rock are slowly rounded by the removal of their outer shells. Often known as onion-skin weathering and typically seen in igneous rocks.
Spinel lherzolites	An olivine rich ultra-basic (very low silica) rock containing the magnesium-rich mineral spinel.
Strata	Rocks that form layers or beds.
Stratigraphy	The definition and description of the stratified rocks of the Earth's crust.
Syncline	A structural term describing a basin- or trough-shaped fold in rock in which rock layers are downwardly concave. The youngest rock layers form the core of the fold and outward from the core progressively older rocks occur.
Talus	A sloping accumulation of loose clasts generally in the form of a wedge, usually found at the base of a steep rock face.
Tetrapods	The first four limbed vertebrates which evolved from lobe-finned fishes.
Throw	The amount of displacement on a fault.
Trachybasalt	A fine-grained extrusive igneous rock of basic composition (see Appendix 3)
Tuff	A rock formed of consolidated fine-grained volcanic ash ejected during a volcanic eruption.
Turbidite	A deposit from a turbidity current which is sediment which has flowed via gravity e.g. at the edge of a continental shelf. The sequence of sediment usually fines upwards.
Unconformable	A term generally applied to younger strata that do not conform in position or that do not have the same dip and strike as those of the immediately underlying rocks. Also applies to the contact between unconformable rocks.
Unconformity	A surface of contact between two groups of unconformable strata. Represents a break in the geological record where a combination of erosion and lack of deposition was taking place.
Vein	A fracture in the rock infilled with secondary minerals, often quartz or calcite.
Vesicles	Small spherical or elliptical cavities in an igneous rock which represent bubbles of gas which existed in the hot magma. Before the gas could escape, the magma cooled and hardened, 'trapping' the gas bubbles in the rock.
Wacke	A texturally immature sandstone with a fine-grained matrix which forms 15–75% of the rock (informally termed 'greywacke')
Xenoliths	A foreign crystal or rock fragment which becomes enveloped within a larger rock during its development.

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