British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

East Lothian Geodiversity Audit

Geology and Landscape Scotland Programme

Open Report OR/14/063

BRITISH GEOLOGICAL SURVEY

Geology and Landscape Scotland Programme

Open Report OR/14/063

East Lothian Geodiversity Audit

K Whitbread, R Ellen, E Callaghan, J E Gordon and S Arkley

Keywords

East Lothian, Geodiversity, Quaternary, Carboniferous, Devonian, Silurian-Ordovician.

Front cover

Image: View of Dunbar shore, looking North-west. © Sarah Arkley, BGS/NERC

Bibliographical reference

WHITBREAD, K, ELLEN, R, CALLAGHAN, E, GORDON, J E AND ARKLEY, S 2015. East Lothian Geodiversity Audit. *British Geological Survey Open Report*, OR/14/063. 192pp.

Edinburgh, Scotland British Geological Survey 2015

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488

email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683

email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270

Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Forde House, Park Five Business Centre, Harrier Way, Sowton EX2 7HU

Tel 01392 445271 Fax 01392 445371

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501

www.nerc.ac.uk

Website www.bgs.ac.uk

Shop online at www.geologyshop.com

Foreword

Constant development pressure on Scotland's land and resources demands a greater awareness and understanding of the dynamics of our natural world in order to deliver a sustainable environment for the future. Geodiversity is an important environmental asset, linking people, places, rocks, soils, landscape and ecosystems, but it remains one of the least recognised and appreciated.

In East Lothian, several nationally and internationally important geological sites have previously been identified and protected by statutory measures (Sites of Special Scientific Interest). However, these sites form only a limited part of the area's geodiversity. In order to recognise and protect a broader range of important geological and geomorphological features in East Lothian, East Lothian Council has commissioned the British Geological Survey (BGS) to audit and assess the geodiversity of East Lothian.

This report produced by BGS is a systematic inventory and evaluation of geodiversity sites in East Lothian. This audit has the potential to help inform planning policy and planning decisions with respect to the protection of the area's geodiversity. It also may provide an information resource to support education, and management activities that promote the preservation of geodiversity sites and geological resources.

Acknowledgements

This project was funded by East Lothian Council and the British Geological Survey.

The authors wish to express their thanks to Jean Squires and Stuart MacPherson from East Lothian Council. We are indebted to John Gordon for the survey of Quaternary sites and contribution to the report. Information on potential sites was provided by David McAdam, Mike Browne and Angus Miller from Lothian and Borders GeoConservation Group.

Contents

FIGURES

TABLES

Summary

This report describes a geodiversity audit of East Lothian carried out by the British Geological Survey (BGS) on behalf of East Lothian Council (ELC). The audit comprised a desk review of potential geodiversity sites, field assessments, evaluation of the geodiversity sites and reporting.

Potential local geodiversity sites were identified by contacts in the Lothian and Borders Geoconservation Group (formerly RIGS). Information on the potential sites from BGS records and published sources was reviewed, including digital geological maps and historic field slips, digital aerial photography, and published papers, memoirs and reports. Documentation for sites previously identified as Sites of Special Scientific Interest (SSSI) and/or Geological Conservation Review (GCR) sites was also reviewed. Due to their current protected status, sites designated as SSSIs for their geological features were not selected for the geodiversity audit with the exception of coastal sites located within the large Firth of Forth SSSI notified for both biological and geological features.

Field assessments of 30 of the sites identified by Lothian and Borders Geoconservation with the highest potential geodiversity value were conducted during 2014. Information on the geoscientific merit, cultural heritage, economic importance, access, site condition and fragility education potential, and community associations of the sites was recorded. Geoscientific merit is evaluated in terms of the rarity and quality of the features displayed at the site.

A total of 21 bedrock or mixed bedrock and Quaternary sites, and 9 Quaternary sites were identified as candidates for designation as local geodiversity sites in East Lothian. The sites selected include the best examples of geological and geomorphological features in the region and are considered to be representative of the diverse range of geological strata and landforms that characterise the geology of the region. The sites include excellent examples of Carboniferous, Devonian and Silurian/Ordovician strata that are exposed across central and southern Scotland, and landforms that are classic examples of Quaternary glacial features in lowland terrains and important coastal geomorphology systems. The sites also have numerous links to the character of the landscape, historical features, ecology, and the economic and cultural history of the area.

Many of these sites have the potential to be enhanced through interpretation to encourage visitors and students to learn more about geology and the relationship between rocks, landscape and ecosystems, and the links between the geology and the economic and cultural heritage of the East Lothian area.

1 Introduction

The British Geological Survey (BGS) was commissioned by East Lothian Council (ELC) to carry out a review of sites of geological and geomorphological significance within the local authority area. The study has taken the form of a geodiversity audit to assist in future planning, development and conservation issues. The work was co-funded by BGS Scotland.

This work was undertaken in the spring and summer of 2014 with a desk-top review of BGS records and published literature followed by field visits to gather new geodiversity information. This report describes, illustrates and evaluates 30 geological sites in East Lothian that are considered to best represent the geological diversity of the area.

Recommended boundary lines defining the site areas have also been supplied to ELC in GIS format (ESRI Shapefile) to supplement the information provided in this report. The Shapefile version of the boundary lines should be regarded as the definitive version for reference purposes.

1.1 BACKGROUND

East Lothian Council recognises the importance of conserving the region's geodiversity and preserving landscape features, in particular those geological features that may be considered as Local Geodiversity Sites (formerly termed Regionally Important Geological and Geomorphological Sites or RIGS).

Nationally designated sites such as Sites of Special Scientific Interest (SSSIs) or Geological Conservation Review sites (GCRs) protect only a limited part of the area's geodiversity. ELC have commissioned the BGS to evaluate a range of geological and landscape features in East Lothian in addition to those that currently have SSSI status. The audit builds on previous work by volunteers of the Lothian and Borders Geoconservation group in identifying and describing many of the areas important geological features.

The audit of East Lothian Geodiversity is intended to form the basis for designation and protection of Local Geodiversity Sites, with a comparable status to Local Biodiversity Sites within the planning framework. The audit will also provide ELC with information that may be used to enhance the quality of their geological sites and to develop public engagement and education initiatives.

1.2 AIMS AND OBJECTIVES

The principal aim of the study is to identify and formally assess the key geodiversity sites in East Lothian. These sites are selected to represent the diverse geology and geomorphology of the area.

The objectives of the study are:

1. To review existing designated geological sites (SSSIs) and identify potential geodiversity sites with no current designation.

2. To evaluate the geodiversity of each site based on criteria that consider the scientific, educational, cultural and community merits.

3. To delineate site boundaries that encompass the key geological features of the site and sufficient area to allow them to be viewed,

4. To review the condition of the sites and, where appropriate, to make suggestions for potential improvements in the management, access and education potential of the site.

1.3 METHODOLOGY

The objectives have been addressed through three stages of work: an initial desktop review of published literature and BGS archive records to identify potential sites; field assessments of the geodiversity sites; and finally analysis and reporting of the geodiversity valuations.

1.4 STRUCTURE OF THE REPORT

An overview of the geology of East Lothian is presented in chapter 2, including the bedrock (solid) geology and the overlying Quaternary (superficial) deposits. Chapter 3 describes the methods used to identify potential geodiversity sites, the criteria used in their evaluation and the procedures used in the field assessments.

Chapter 4 provides detailed site assessments for each of the geodiversity sites, and forms the main part of the report. The information is presented as a set of pro-forma sheets containing:

- General location and background information
- A location map
- A summary description
- A review of the condition, access and safety of the site
- An assessment of the sites GeoScientific Merit
- The site evaluation (including the overall Geodiversity value statement)
- A review of the cultural, heritage and economic associations
- Site Photographs

The results of the audit are summarised and discussed in chapter 5.

1.5 WHAT IS GEODIVERSITY?

Geodiversity has many definitions, but essentially describes the variety of rocks, minerals and fossils, landforms and landscapes, active geological processes and soils and subsoils (Quaternary deposits) of an area. These elements interlink and together determine not only the form our natural environment but also the character of local wildlife habitats and ecosystems.

Geodiversity also has strong links to the social, cultural and economic heritage of the people of East Lothian. The locations of settlements, abstraction of minerals and the use of local stone in buildings and infrastructure give a distinct character to the region and typify the strong links between our human heritage and our geodiversity.

1.6 WHY CONSERVE GEOLOGICAL FEATURES

Despite wide preservation and protection of biodiversity sites, the geodiversity that underpins the stability of ecosystems and contributes to our economic, social and cultural heritage has only limited protection within the planning system. Current protection for geological sites in Scotland is restricted to the sites that are designated as SSSIs.

Geodiversity is an integral part of nature. It has intrinsic (geoheritage), scientific, educational, cultural, ecological and ecosystem service values. These values are vulnerable to a wide range of threats; quarries can be infilled, natural overgrowth by vegetation can obscure exposures,

features within an urban environment may be built over, and landforms may be removed or remodelled during excavation or development. Our understanding of the geological processes and landscape history of Scotland, and the wider UK, depends on access to key sites from which the diverse nature of rocks can be directly observed. These sites preserve our geological heritage. They are fundamental not only for scientific research and education, but often have cultural and aesthetic values that provide connections between people and place. Many also support highly valued ecosystems, habitats and species, while others are assets for recreation and tourism. Hence, it is vital that geodiversity sites are protected so that our geoheritage can be maintained and appreciated by future generations.

2 East Lothian's Geoheritage

The East Lothian Council area lies in the south east of Scotland, bordered by the Firth of Forth and the North Sea on its northern and eastern sides, and by the Scottish Borders to the south and Midlothian (/Edinburgh) to the south and west (Figure 1).

East Lothian is renowned for its attractive rural landscape and beautiful coastline. These features have their origins in the underlying geology and the geological processes that act upon the land. The diverse bedrock that underlies East Lothian has been sculpted by the erosion of rivers, glaciers and the sea over recent geological past (the Quaternary period). Landforms and deposits from the recent processes form characteristic features in the landscape. Furthermore, the picturesque towns and villages owe their distinct regional character to the local stone used in the walls and buildings.

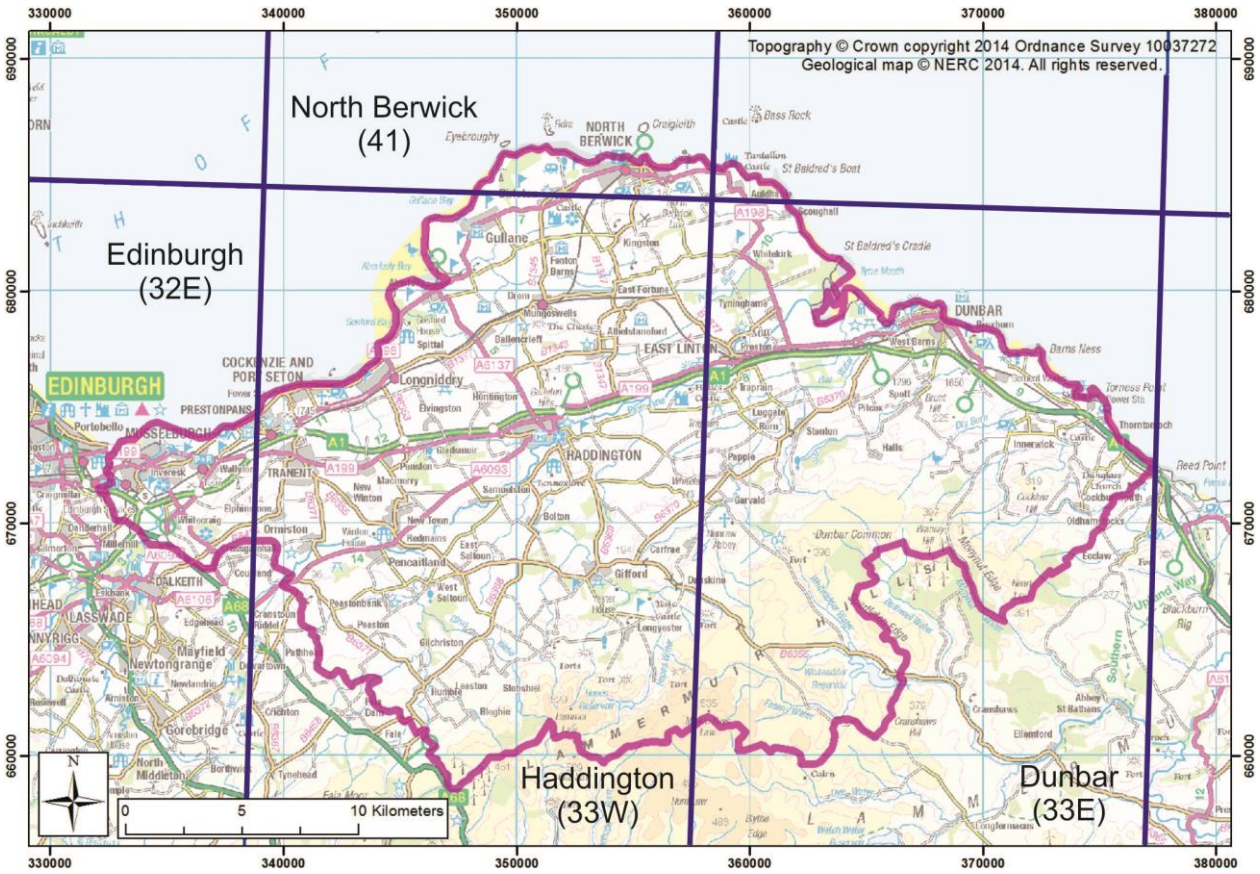


Figure 1 Location of East Lothian Council area (pink outline) and the distribution of 1: 50 000 scale BGS geological map sheets (blue lines).

In the following review of the bedrock and superficial (Quaternary) geology of East Lothian, information was derived from the published geological maps of the area; BGS 1: 50 000 scale map sheets 32E (Edinburgh), 33W (Haddington), 33E (Dunbar), 41 (North Berwick), and the geological memoir for Haddington (McAdam and Tulloch, 1985).

2.1 BEDROCK GEOLOGY

East Lothian lies across the south-eastern margin of the Midland Valley of Scotland. The Midland Valley is the name given to the relatively low lying part of central Scotland located between the uplands of the Scottish Highlands to the north and the Southern Uplands to the south. Geologically it is defined by two large fault systems: the Highland Boundary Fault, which lies to the north and extends from Stonehaven in the northeast to the Firth of Clyde at Helensburgh, and the Southern Upland Fault which extends from Dunbar to Glen App. The downfaulted area between the two faults contains rocks of mainly Carboniferous and Devonian age (Figure 2, Figure 3).

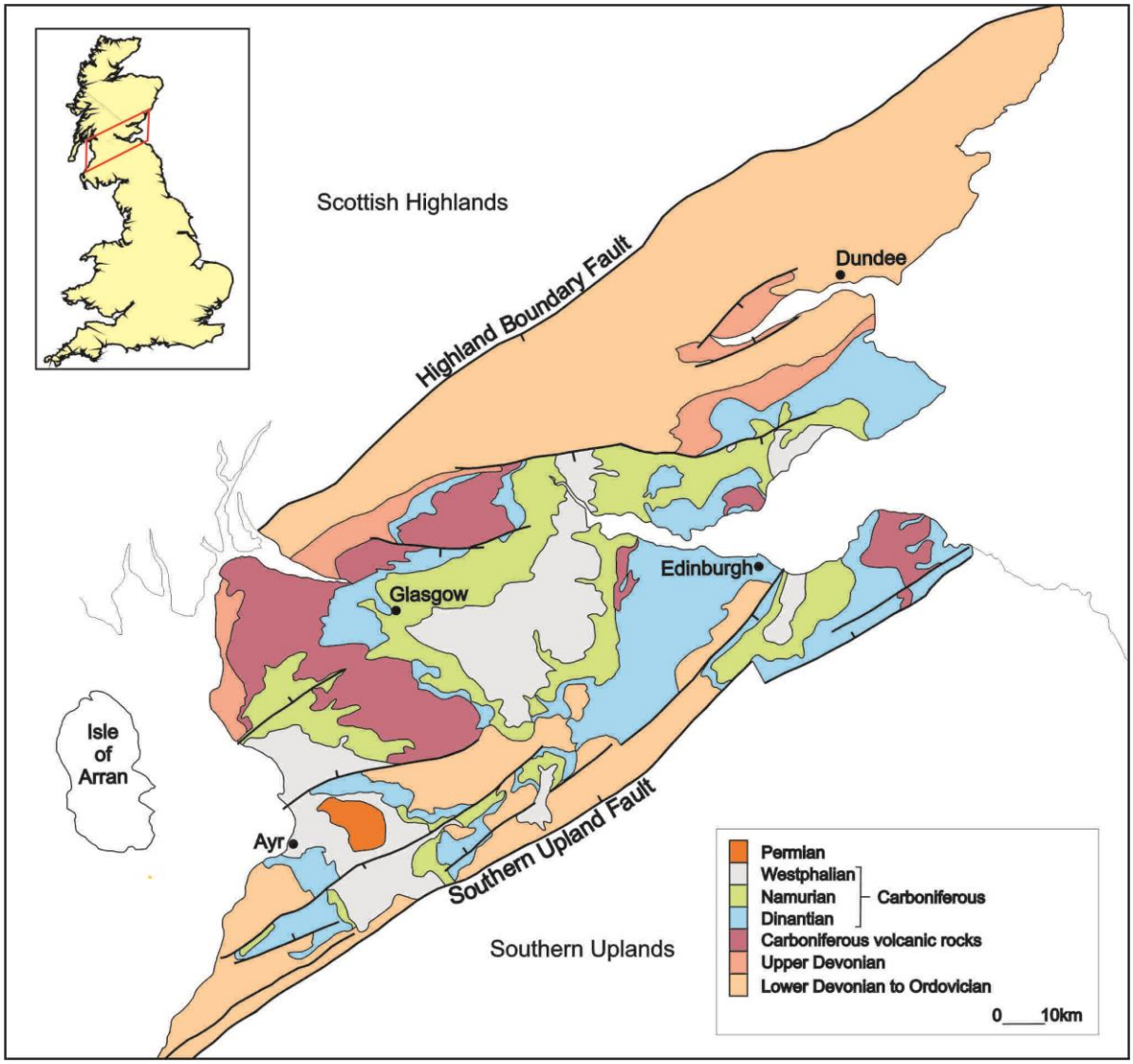
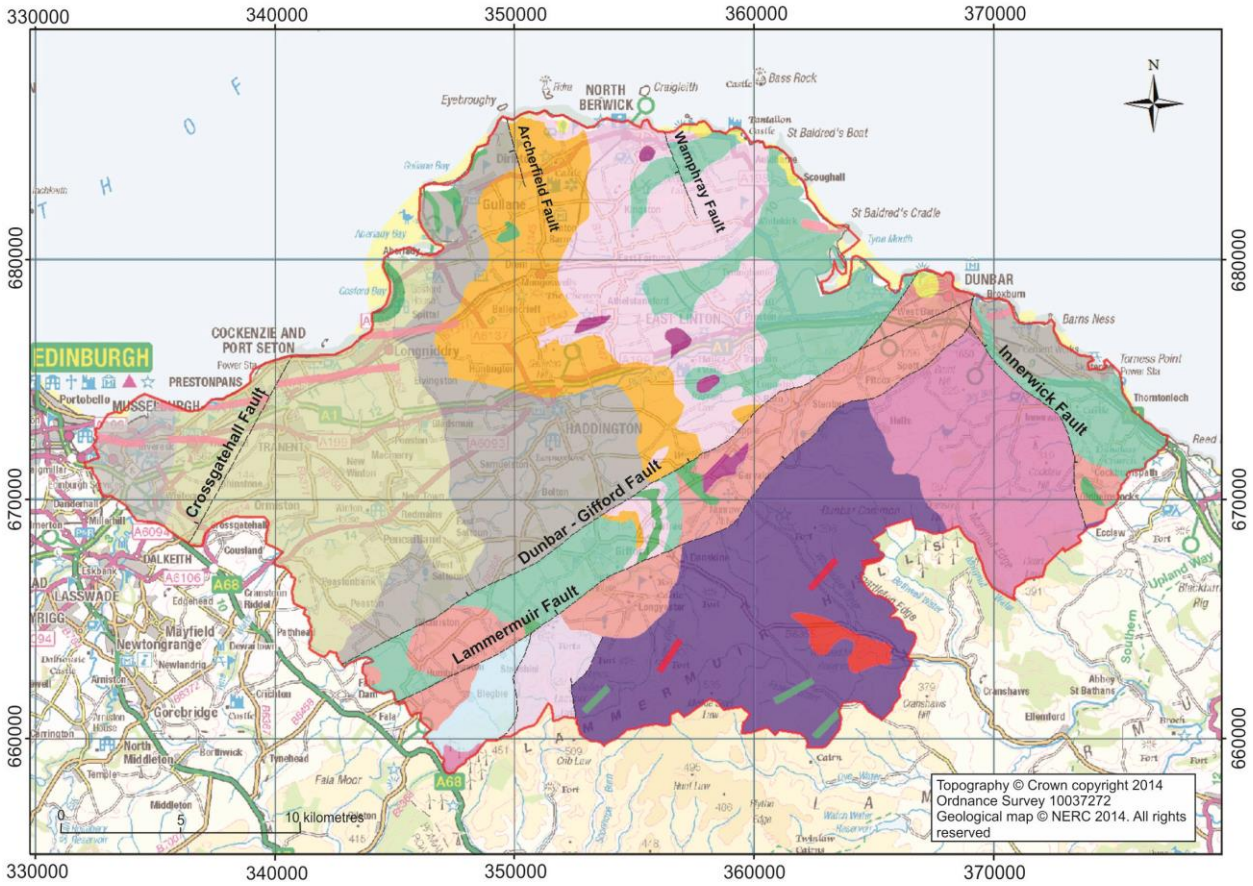


Figure 2 Simplified geological map of the Midland Valley of Scotland. Geological faults are shown by a thick black line with a tick on the downthrown side (Source: BGS DiGMapGB data).



Key

ELC_Boundary

Faults with downthrow indicated

Bedrock Geology 625K

SEDIMENTARY ROCKS

CARBONIFEROUS

- Scottish Coal Measures Group
- Clackmannan Group
- Strathclyde Group
- Inverclyde Group

UPPER DEVONIAN

- Stratheden Group

LOWER DEVONIAN

- Reston Group

SILURIAN

- Gala Group

ORDOVICIAN

- Shinnel Formation and Glenlee Formation
- Portpatrick Formation and Glenwhargen Formation

IGNEOUS ROCKS

EXTRUSIVE

CARBONIFEROUS

- Felsic Lava and Felsic Tuff
- Mafic Lava and Mafic Tuff

} Garleton Hills Volcanic Rocks

INTRUSIVE

CARBONIFEROUS TO PERMIAN

- Felsic Rock
- Mafic Igneous Rock
- Pyroclastic Rock
- Dolerite and Tholeiitic Basalt

LATE SILURIAN TO EARLY DEVONIAN

- Felsic Rock
- Mafic Igneous Rock

Figure 3 Bedrock geology of East Lothian

The Southern Upland Fault bisects the landscape of East Lothian, separating the upland moors of the Lammermuir Hills to the south-east from lower, rolling terrain in the north-west that stretches from Haddington and Pencaitland to the coast. In this area, the Southern Upland Fault system comprises two faults, the southern Lammermuir Fault and the Dunbar-Gifford Fault.

Classification of the Carboniferous strata in the Midland Valley of Scotland

Subsystem	Series		Stage	Lithostratigraphical Units: Formations: Central Coalfield	Ayrshire	Fife	West Lothian	East Lothian	Groups	Old Classifications	
Silesian	Westphalian	C	Bolsovian	Upper Coal Measures					Coal Measures	UPPER (BARREN) COAL MEASURES	
		B	Duckmantian	Middle Coal Measures						MIDDLE COAL MEASURES	PRODUCTIVE COAL MEASURES
		A	Langsettian	Lower Coal Measures						LOWER COAL MEASURES	
	Namurian		Chokerian-Yeadonian	Passage Formation					Clackmannan Group	PASSAGE GROUP	
			Arnsbergian						Bathgate Group		
			Pendleian	Upper Limestone Formation						UPPER LIMESTONE GROUP	
				Limestone Coal Formation						LIMESTONE COAL GROUP	
Dinantian	Viséan		Brigantian	Lower Limestone Formation						LOWER LIMESTONE GROUP	
				Lawmuir Formation		Pathhead Formation	West Lothian Oil-Shale Formation	Aberlady Formation		UPPER OIL-SHALE GROUP	CALCIFEROUS SANDSTONE MEASURES
			Asbian	Kirkwood Formation		Sandy Craig Formation					
			Holkerian to Arundian	Clyde Plateau Volcanic Formation		Pittenweem Formation					
						Anstruther Formation	Gullane Formation		Strathclyde Group	LOWER OIL-SHALE GROUP	
							Arthur's Seat Volcanic Formation	Garleton Hills Volcanic Formation			
			Chadian			Fife Ness Formation					
	Tournaisian		Courceyan	Clyde Sandstone Formation				Ballagan Formation	Inverclyde Group	CEMENTSTONE GROUP	
				Ballagan Formation							
				Kinnesswood Formation						UPPER OLD RED SANDSTONE (part)	

Note: The Laggan Cottage Mudstone Formation of north Arran and the Birgidale Formation of south Bute at the base of the Strathclyde Group are not shown. Nor are the Bathgate hills, Kinghorn and Salsburgh Volcanic formations of the Bathgate Group.

Table 1 Classification of the Carboniferous strata in the Midland Valley of Scotland

Older, Lower Palaeozoic rocks (460 – 430 Ma) crop out to the south of the Lammermuir Fault, represented by fissile sandstones and siltstones known as greywacke that underlie the Southern Upland terrain. In the east, these rocks are overlain by conglomeratic rocks of Lower Devonian age (430 – 390 Ma) that were once deposited over the eroded surface of the Lower Palaeozoic rocks by large rivers.

To the north of the Lammermuir Fault, the rocks that crop out in the East Lothian area are of late Devonian to Carboniferous age (380 – 360 Ma). These rocks consist of a sequence of sedimentary and igneous strata that were laid down in a gradually subsiding basin. During the late Devonian and early Carboniferous, rivers traversing a hot, humid lowland plain deposited sand and mud, which was colonised by early land plants. These sediments later formed the variable sequence of sandstone, siltstone, mudstone, dolomitic limestone and seatearths (preserved soils) known as the Ballagan Formation. The rich late Devonian environment of rivers and shallow-water lakes formed an ideal setting for the evolution of land-going animals (tetrapods), and the study of early tetrapod fossils found in the Ballagan Formation of the Scottish Borders and East Lothian, as well as the environment in which they lived, is a key area of current geological research.

Later Carboniferous rocks (360 – 300 Ma) are represented in East Lothian by a sequence of volcanic and sedimentary strata (Strathclyde Group), with older rocks exposed in the east and younger rocks to the west. The Garleton Hills Volcanic Formation, a sequence of lavas and tuffs (volcanic ash deposits) formed during a period of eruptive volcanism during the mid-Carboniferous, crop out at the base of the Strathclyde Group in the east of the area and are exposed along the coast near North Berwick. Overlying the volcanic rocks to the west are a series of units of sedimentary rocks including sandstones, mudstones and limestones deposited in varying marine, shallow marine, and terrestrial fluvial environments arising from changes in relative sea level during the mid to late Carboniferous. The youngest rocks in East Lothian comprise strata of the Coal Measures Group (Scotland) formed by cyclic deposition of sandstone, mudstone, siltstone and coal in a swampy forest environment crossed by large river systems.

The sequence of Carboniferous rock units in East Lothian is shown in Table 1.

2.2 QUATERNARY GEOLOGY

East Lothian displays a diverse range of glacial and coastal landforms and deposits (Figure 4), which reflect the influence of erosion and deposition during the past 2.6 million years, a time known as the Quaternary period. During the Quaternary, Scotland was covered repeatedly by large ice sheets that extended from the mountains westwards across the continental shelf and eastwards across the floor of the North Sea to merge with Scandinavian ice. Along the coast, the position of the coastal edge changed as sea-levels fell and rose as the glaciers expanded and retreated. In East Lothian, most of the glacial evidence relates to events during the most recent glaciation, the Late Devensian (c. 31 – 11.7 Ka). During this time, large glaciers sourced in the Highlands and Southern Uplands, coalesced in the southern part of the Midland Valley to form a vast sheet of ice that streamed across the area towards the east. Erosion beneath this large glacier has left a legacy of scoured bedrock and streamlined deposits across the East Lothian landscape.

The broad outlines of the landscape of East Lothian reflect differential erosion of the varied sedimentary and volcanic rocks over many millions of years. North of the Southern Upland Fault, the more resistant volcanic rocks generally form areas of upstanding relief that have been streamlined or eroded into crag-and-tail landforms by glacial scouring (e.g. the Garleton Hills, North Berwick Law, Traprain Law). The lower ground is extensively mantled by till which was deposited and streamlined by the glacier ice, and by sand and gravel deposited by meltwater streams flowing beneath or adjacent to the Late Devensian ice sheet. Erratic boulders, including metamorphic rocks of Highland origin, commonly occur along the coast and are particularly well

displayed where they have been washed out of till along the shore platforms. At Kidlaw, a mass of limestone c. 0.2 km^2 forms the largest known erratic in Scotland (Kendall & Bailey, 1908). Meltwater channels carved into till and bedrock by subglacial and ice marginal streams, are common along the northern flanks of the Lammermuir Hills, where they are associated with kame terraces, ice-marginal lake deltas.

As the climate warmed rapidly after 15 ka, the ice retreated from the lowlands and vegetation became established. As the ice receded, relative sea-level rose and the sea invaded the lower parts of the coastline forming Lateglacial raised shorelines along many areas of the East Lothian coast. In the Tyne estuary, cold-water estuarine deposits containing arctic marine fossils were laid down adjacent to the retreating glaciers. In a former claypit at West Barns, bones of a Ringed seal (*Phoca hispida*) were also recovered (Peacock, 1999; Davies et al., 1986). The subsequent return of a severely cold climate gave rise to periglacial conditions between 12.9 – 11.7 ka. During this period, slope and fluvial activity were enhanced; thick slope deposits (head) accumulated on the lower slopes of the Lammermuir Hills, and talus formed in the Garleton Hills.

During early postglacial times, a further period of higher relative sea level culminated after around 7000 years ago. Subsequent changes in relative sea level produced further raised shorelines along many parts of the coast. As the sea dropped to its present level, continued reworking of the coastal sediments has formed extensive sandy beach and sand dune systems in many bays, as well as areas of mudflats and saltmarshes. In an embayment at Lochhouses, 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 landslide on the Norwegian slope 8100 years ago (Smith et al., 2004).

Erosional coastal landforms including shore platforms and cliffs of various ages occur along the coast. The interplay between coastal erosion and the different volcanic and sedimentary rocks has produced a variety of distinctive headlands, stacks, natural arches and cliffed islands such as the Bass Rock.

Inland from the coast, postglacial rivers have adjusted to changing discharges and sediment loads as reflected in terrace formation, floodplain development, abandonment of meanders and abandoned channels including those on the lower River Tyne. On upland slopes, gullying processes in weathered bedrock have resulted in the formation of areas of ‘badland’ topography in the Lammermuir Hills (Werritty & McEwen, 1997).

2.3 GEOLOGICAL SSSIs IN EAST LOTHIAN

Sites of Special Scientific Interest are areas designated by Scottish Natural Heritage (SNH) under the Nature Conservation (Scotland) Act 2004. These sites are representative of features of our natural heritage and include examples of plant and animal habitats, rocks and landforms that are considered to be nationally important.

There are 15 SSSIs in the East Lothian area, of which seven have been designated wholly or in part due to their geological or geomorphological features (Table 2). With one exception, the large Firth of Forth SSSI, the geological SSSIs have not been included as geodiversity sites in this audit due to their pre-existing designation. The geological SSSIs should be viewed as key geodiversity sites in conjunction with the sites identified in this report.

The Firth of Forth SSSI covers 74 km^2 of coastline along the full length of the northern and southern margins of the Firth of Forth, including many areas of the East Lothian coast. This large SSSI has been designated for both its biological and geological importance. However, the size of the site means that particular geological significance of specific areas of the East Lothian coast included within the SSSI is not fully represented. Geodiversity sites located along sections of the East Lothian coastal zone that fall within the Firth of Forth SSSI have been identified in this

report. The designation of these sites within the Firth of Forth SSSI is noted in the site assessments.

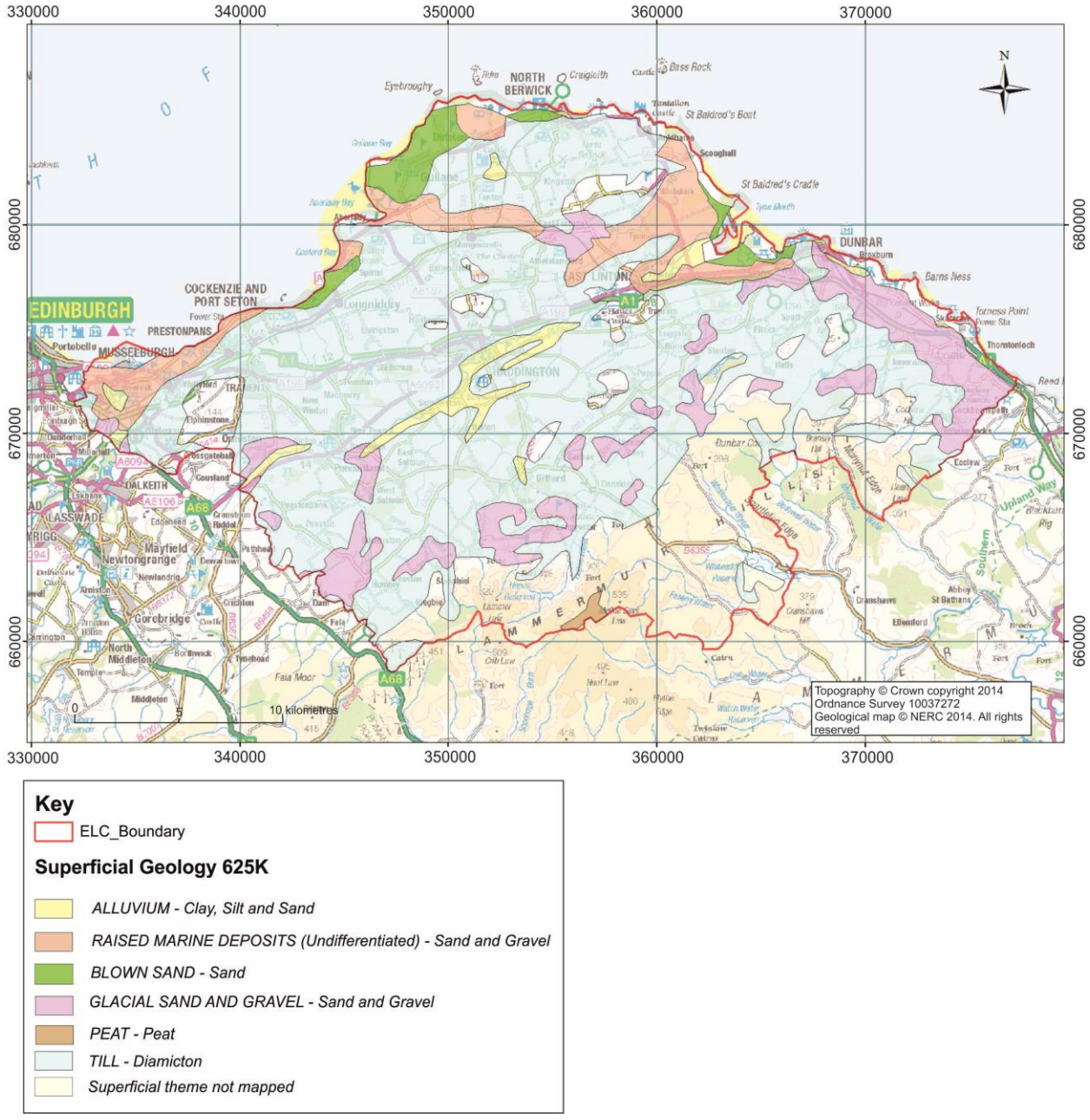


Figure 4 Superficial deposits of East Lothian

SSSI	Type	Notified geological features	Site Code
Bangley Quarry	Geological	Mineralogy	145
Barns Ness	Geological and Biological	Stratigraphy (Lower Carboniferous)	153
Garleton Hills	Geological	Igneous petrology (Carboniferous – Permian)	671
Keith Water	Geological	Quaternary geology (glacial deposits)	828
Rammer Cleugh	Geological and Biological	Quaternary geology (glacial landforms)	1327
Traprain Law	Geological and Biological	Igneous petrology (Carboniferous – Permian)	1560
Firth of Forth	Geological and Biological	Stratigraphy, igneous petrology, palaeontology, Quaternary geology and geomorphology	8163
Bass Rock	Biological	-	155
Danskine Loch	Biological	-	496
Forth Islands	Biological	-	653
Lammer Law	Biological	-	903
Lammermuir Deans	Biological	-	904
North Berwick Law	Biological	(This site was formerly noted for igneous petrology)	1228
Papana Water	Biological	-	1270
Woodhall Dean	Biological	-	1646

Table 2 Sites of Special Scientific Interest in East Lothian

2.4 GEOLOGICAL RESOURCES AND THE BUILT HERITAGE

Geological resources include building stones and minerals that are extracted for construction materials and energy generation. In the west of East Lothian, coal has been extracted from strata of the Coal Measures Group since the 13th century and the landscape bears many reminders of the former mining activity including disused shafts and adits. The mining heritage has also influenced the development of towns and villages in the area and is reflected in many of the local place names. In addition to mining, industries such as brick production have historically provided other important connections between the geology and the economy of East Lothian.

Local sandstone, extracted from numerous small quarries in the Carboniferous sedimentary strata, has been used in many of the historic buildings found in East Lothian from the region's castles to its cottages. The use of local stone lends a distinct character to many of the picturesque villages.

Igneous rocks have also been quarried in many areas for road stone. Small but distinctive quarries are found on some of the prominent igneous landforms of the region such as Traprain Law (and SSSI) and North Berwick Law. Quarries in the extrusive igneous strata of the Garleton Hills were important early sites for the study of these rock types. Several quarries in the region became type sites for early classification schemes of volcanic rocks with the names of the quarries used to denote the distinct types of basaltic rocks they contain (e.g. Dunsapie and Markle).

The distinct rocky coastline of East Lothian has exerted an important control on the siting of harbours and their associated towns and villages. The strong geological influence on the form of the harbour and its development is evident in Dunbar for example. The strategic importance of these harbours for trade and commerce can also be seen in the presence of historic military sites (including castles) along the East Lothian coast.

3 Evaluating East Lothian's Geodiversity

3.1 AUDIT SITE SELECTION: DATA SOURCES AND CRITERIA

Potential geodiversity sites were identified by review of available documents and datasets, and through consultation with members of Lothian & Borders Geoconservation. Information sources consulted included:

- SSSI and GCR documentation (SNH)
- BGS 1:10 000 geological standards maps and fieldslips
- BGS BritPits database of Mines and Quarries
- The Haddington Geological Memoir (McAdam and Tulloch, 1985)
- Lothian Geology: An excursion guide (A D McAdam & E N K Clarkson, 1986)
- Existing scientific literature

From this assessment, 31 potential geodiversity sites were identified for field assessment (Table 3, Figure 5) based on their geoscientific merit according to criteria for valuing the educational, scientific, historical and aesthetic value of sites developed by GeoConservation UK (RIGS).

The selection of sites was made to ensure a comprehensive geological and geographical spread within the East Lothian area, with a focus on the highest quality and most significant geological features of the region.

3.2 GEODIVERSITY AUDITING

Field auditing was carried out between March and December 2014 by BGS staff (Rachael Ellen, Elieen Callaghan, Sarah Arkley, Katie Whitbread, Hugh Barron and David Millward), with assistance from Mike Browne (Lothian and Borders Geoconservation). The Quaternary sites were audited on behalf of the BGS by John Gordon (Scottish Geodiversity Forum). The criteria used to evaluate the sites are discussed below. As far as possible landowners were contacted prior to visiting or accessing sites, but it was not possible to establish ownership for every site visited.

Data were collated digitally in ARC GIS and reviewed with information from aerial photography, Ordnance Survey topographic maps and BGS digital geological datasets. Site boundaries (discussed below) and key audit data have been supplied to ELC in conjunction with this report.

Of the 31 potential local geodiversity sites identified for field assessment, full audits were conducted at 30. The remaining site, several disused sandstone quarries near Gullane was not audited as the quarries are now fully overgrown and no rock exposures were found.

3.3 DEFINING SITE BOUNDARIES

The site areas have been delineated through the generation of Shapefiles in ESRI ArcGIS. The method used for delineating site boundaries was developed in discussion with East Lothian Council officers.

The **site boundary** defines the total area considered to be integral to the geodiversity site and is consistent with a suggested protection zone that is considered to necessary to maintain the integrity of the geodiversity site.

The site boundary may comprise one or a number of areas of **exposed geological features** including rock outcrops, **landforms** and any adjacent **geologically significant areas** considered integral to the site due to landscape and access considerations. In coastal areas, the site boundaries extend offshore to the Mean Low Water Springs defined on Ordnance Survey 1:10,000 scale topographic maps.

The site boundaries are displayed in the maps in the attached site valuations and have been provided as a separate ArcGIS Shapefile. The Shapefile should be regarded as providing the definitive site boundary for reference purposes.

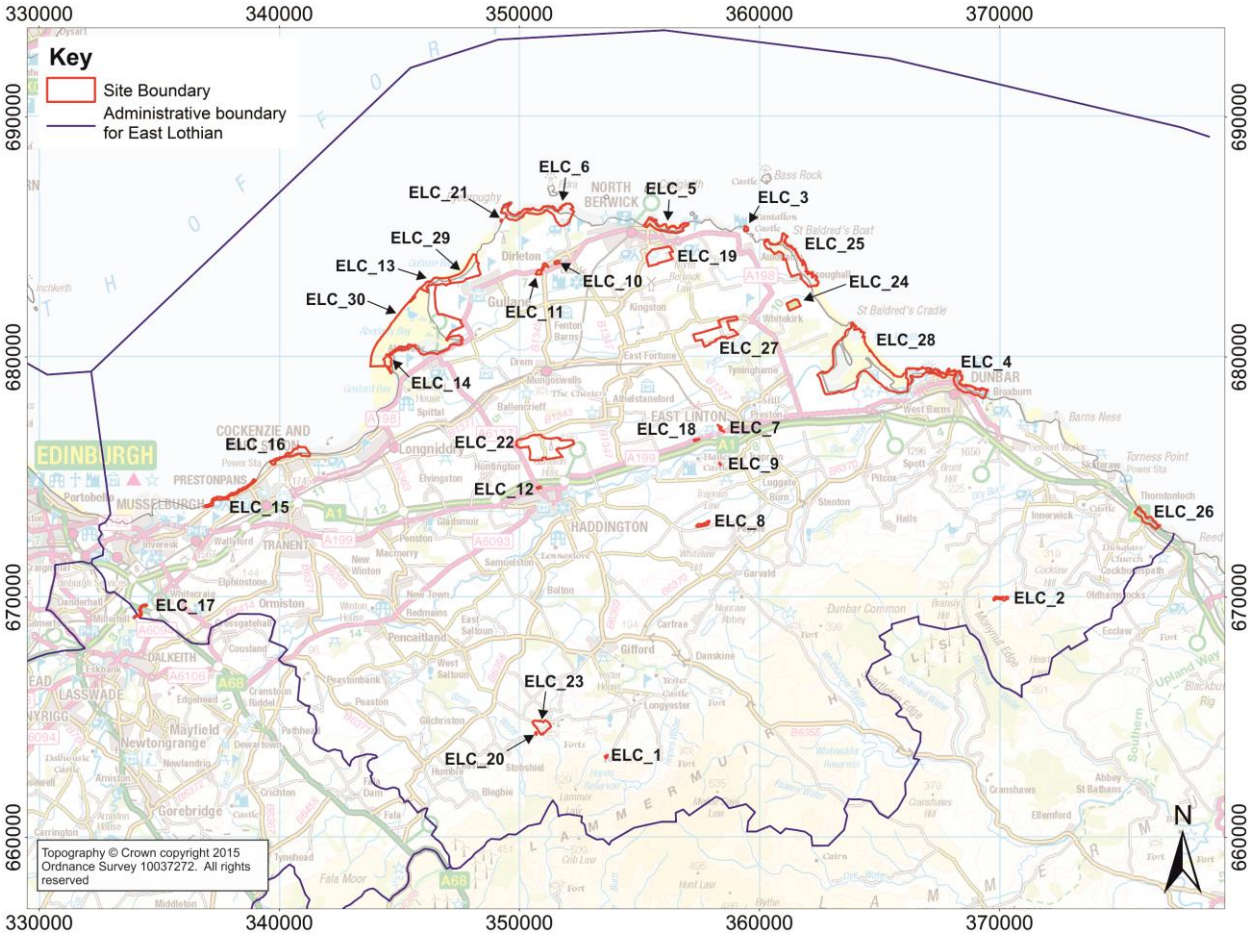


Figure 5 Location map of East Lothian Geodiversity Sites

No	Site	Easting	Northing	Main feature(s)
ELC_1	Gala Law Quarry	353607	663348	Lower Palaeozoic rocks, fossils
ELC_2	Burn Hope	370105	669951	Lower Devonian sedimentary rocks, fluvial geomorphology
ELC_3	Gin Head (Tantallon)	359439	685331	Lower Carboniferous palaeontology
ELC_4	Dunbar Shore	368100	679300	Carboniferous intrusive igneous and sedimentary rocks (Ballagan Formation), coastal geomorphology
ELC_5	North Berwick Shore	356026	685471	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation), coastal geomorphology
ELC_6	Yellow Craigs Shore	350749	686061	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation)
ELC_7	Old Markle Quarry	358385	677010	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation)
ELC_8	Blaikie Heugh, Balfour Monument	357631	673049	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation), landscape
ELC_9	Kippielaw	358373	675519	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation)
ELC_10	Dirleton Castle	351616	682954	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation), historical association
ELC_11	Craigs Quarry	350852	683556	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation)
ELC_12	Peppercraig Quarry	350800	674500	Carboniferous volcanic rocks (Garleton Hills Volcanic Formation), historical association
ELC_13	Gullane Shore	346590	683094	Carboniferous sedimentary rocks (Gullane Formation), coastal geomorphology
ELC_14	Kilspindie Shore and Aberlady Point	344707	680205	Carboniferous sedimentary rocks (Aberlady and Lower Limestone formations), coastal geomorphology
ELC_15	Prestonpans Shore	338063	674308	Upper Carboniferous sedimentary rocks (Limestone Coal and Upper Limestone formations)
ELC_16	Cockenzie to Port Seton Shore	340377	675935	Upper Carboniferous sedimentary rocks (Upper Limestone, Passage and Lower Coal Measures formations)
ELC_17	Esk Valley	334206	669403	Middle Coal Measures Formation
ELC_18	Pencraig Quarry	357286	676536	Intrusive igneous rocks
ELC_19	North Berwick Law	355847	684235	Geomorphology and Carboniferous plugs
ELC_20	Kidlaw Quarry	350689	664322	Intrusive igneous rocks
ELC_21	Cheese Bay	349242	685684	Carboniferous palaeontology
ELC_22	Garleton Hills	351017	676294	Glacial landforms
ELC_23	Kidlaw Errattic	350976	664604	Glacial deposit and landforms
ELC_24	Lochhouses	361415	682176	Coastal deposits
ELC_25	Seacliff, Scoughall Shore	361506	684062	Coastal landforms
ELC_26	Thorntonloch	376110	673220	Coastal landforms (sandstone)

ELC_27	Whitekirk	358181	681015	Glacial landforms
ELC_28	Tyne Estuary & Belhaven Bay	364408	679790	Coastal landforms
ELC_29	Gullane Bents	347961	683605	Coastal dune system
ELC_30	Aberlady_Bay	346004	681262	Coastal landforms
-	Gullane Sandstone Quarries			No exposures, partially infilled and overgrown

Table 3 List of geodiversity sites in East Lothian and sites visited but not included as geodiversity sites.

3.4 GEOLOGY AND GEOSCIENTIFIC MERIT

The geodiversity site is considered to be represented by the area within the Site Boundary. The assessment of the site condition and valuation of the geodiversity applies to all components of the site that lie within the Site Boundary area.

3.4.1 Site Type

Geodiversity sites are classified according to the type of exposure or feature and the current use of the site (Table 4, Table 5).

3.4.2 Stratigraphy and Rock Types

The chronostratigraphic age (e.g. 'Carboniferous'), lithostratigraphic group and formation (Table 1), as well as the main lithogy for each site are recorded for reference purposes. More details of the main lithologies, their relation to any sub-lithologies that may be present, and the nature of geological structures or other features of interest are given in the geological description.

Site type	Description
Natural Section	Natural outcrop of one or more geological features forming a linear exposure (river section, cliff face, shoreline etc)
Natural Exposure	Natural outcrop of geological feature
Natural Landform	Constructional or erosion geomorphological feature (valley, crevasse, dune, all Quaternary features etc)
Natural View	Collection of geological features forming a landscape overview interpretation
Mine Workings	Feature produced by minerals/coal workings (adit, spoil, hush etc)
Quarry Workings	Feature produced by stone/aggregate workings (quarry, pit, waste dumps etc)
Artificial Section	Section exposure created artificially by work to construct a road/track/path etc
Excavation	Artificially created exposure (excavation - not related to any of the above)

Table 4 Site Type classification scheme

Current Use	Description
In Use	Feature still used for primary purpose (working quarry etc) as defined by the FEATURE criteria
Disused	Feature no longer used for primary purpose and has no other current use
Urban	Feature is on publicly accessible lands (but not recreational lands) within the urban limits (allotments, road verges etc)
Open Country	Feature is on natural countryside with no unique use (mountains, national park land etc.)
Agricultural land	Feature is used/forms part of land used for agricultural purposes (farm fields and grazing areas etc)
Recreation	Feature is on land specifically designed or modified for recreational uses (parks, picnic areas, etc)
Industrial	Feature is on land used for industrial purposes (including waste land forming part of/owned by an industrial complex)
Domestic	Feature falls within the limits of private lands associated with dwellings (gardens, stately home grounds etc)

Table 5 Current Use classification scheme

3.4.3 Geoscientific Merit Criteria

The geodiversity sites have been evaluated according to their geoscientific importance which has been assessed in terms of the relative rarity and quality of key geological or geomorphological attributes that can be seen at the site. The key attributes assessed are:

- **Lithostratigraphy** – features indicative of an important stratigraphic horizon and helping to define the sequence of geological strata,
- **Sedimentology** – features related to depositional processes and settings,
- **Igneous/Mineral/Metamorphic** – intrusive or extrusive igneous rocks, metamorphic rocks and minerals, and mineral vein deposits,
- **Structural geology** – faults, folds, shear zones or other deformation features,
- **Palaeontology** – fossils or trace fossils,
- **Geomorphology** – landforms and features representative of, or demonstrating, key depositional and erosional processes occurring at the earth's surface.

A single site may have more than one attribute, but is unlikely to have all of them. The rarity and quality of the site attributes have been scaled using the classification schemes defined in Table 6.

Where published materials, such as articles or books, provide details of aspects of the sites geology, the literature sources are also noted. Unpublished materials such as leaflets may be available for some sites, and may be mentioned elsewhere in the site report.

An overall geoscientific merit value statement represents the overall geoscientific value of the site using the rarity and quality scales in Table 6. The overall value summarises the scaling for the relevant attributes, but also includes consideration of the relative importance of the site in terms of its geological uniqueness or conversely, the degree to which it is representative of a larger terrain or unit. For instance a site may be of high value because it is extremely rare, but also because it is an excellent example of rocks that are characteristic of a particular geological terrain or time period.

Rarity	
International	Few examples world-wide
National	Few UK examples
Regional	Few Midland Valley examples
Local	Few examples in East Lothian
Quality	
Excellent	Exceptional preservation and exposure of features
Good	Well preserved and exposed features
Moderately Good	Moderately well preserved and exposed features
Poor	Poorly preserved and exposed features

Table 6 Geoscientific Merit criteria (NB: Midland Valley refers to the region between the Southern Uplands in the south and the Highland Boundary Fault in the north)

3.5 CULTURAL, HERITAGE AND ECONOMIC IMPORTANCE

Known associations between the geodiversity of a site and people (whether locally or nationally) are discussed in terms of aesthetic, historical and economic associations. Cultural associations may include literary, aesthetic, musical or social connections, or sites that have significance for the development of the study of the earth sciences. Historical associations may reflect past military, religious or cultural connections, particularly those associated with strategic landform sites. The extraction of building stone and natural resources including coal and lime are considered in terms of economic associations, these may be active or historic.

The potential uses of the site for research, higher/further education, school education or community development were considered along with potential development activities or information materials that could enhance the use of the site by the local community, education groups and other visitors.

3.6 SITE CONDITION, ACCESS AND SAFETY

3.6.1 Access and Safety

The nature of access routes to enter or view sites is an important consideration. The ease of road access and parking, near to the site, along with considerations of the safety of access paths and the safety and condition of the exposure are described in the site report.

Current conflicting activities and restricting conditions, such as tides, shooting restrictions and other activities for which the sites may be used are noted in the report. These are known activities only, and it should be noted that there may be further restrictions to site access that are not known to the authors. Visitors to the sites are responsible for preparing their own risk assessments where necessary. The Scottish Outdoor Access Code provides further information on land access in Scotland.

3.6.2 Fragility

The condition of each site and the stability of rock or sediment exposures were assessed visually during the field survey. Full ground stability assessments were beyond the scope of the survey. Factors affecting the condition of rock exposures at the sites include weathering/erosion, natural overgrowth of vegetation, the effects of sample/fossil collecting, fly tipping and the dumping of waste and construction or other development activities.

4 Site Assessments

This section contains the completed audit forms giving details of each site, geological descriptions, and the geodiversity value.

ELC_1: Gala Law, Lammermuir Hills

Site Information

Location and Summary Description:

The site is a small quarry situated on the eastern slope of Gala Law, located at the northern edge of the Lammermuir Hills, 11 km south of Haddington, and 2 km north-east of Lammer Law. The quarry exposes a sequence of greywackes, siltstones, mudstones and shales belonging to the Gala Group of Silurian Age.

National Grid Reference: Mid-point: 353607, 663348 West-end: 353566, 663360 East-end: 353627, 663355	**Site type**: • Artificial Quarry Works
Site ownership: Not known	Current use: Quarry is an active borrow pit
Field surveyors: Hugh Barron and Rachael Ellen	Current geological designations: None
Date visited: 25/09/2014	Other designations: Within the Lammermuir AGLV, Lammermuirs Local Biodiversity Site.

Site Map

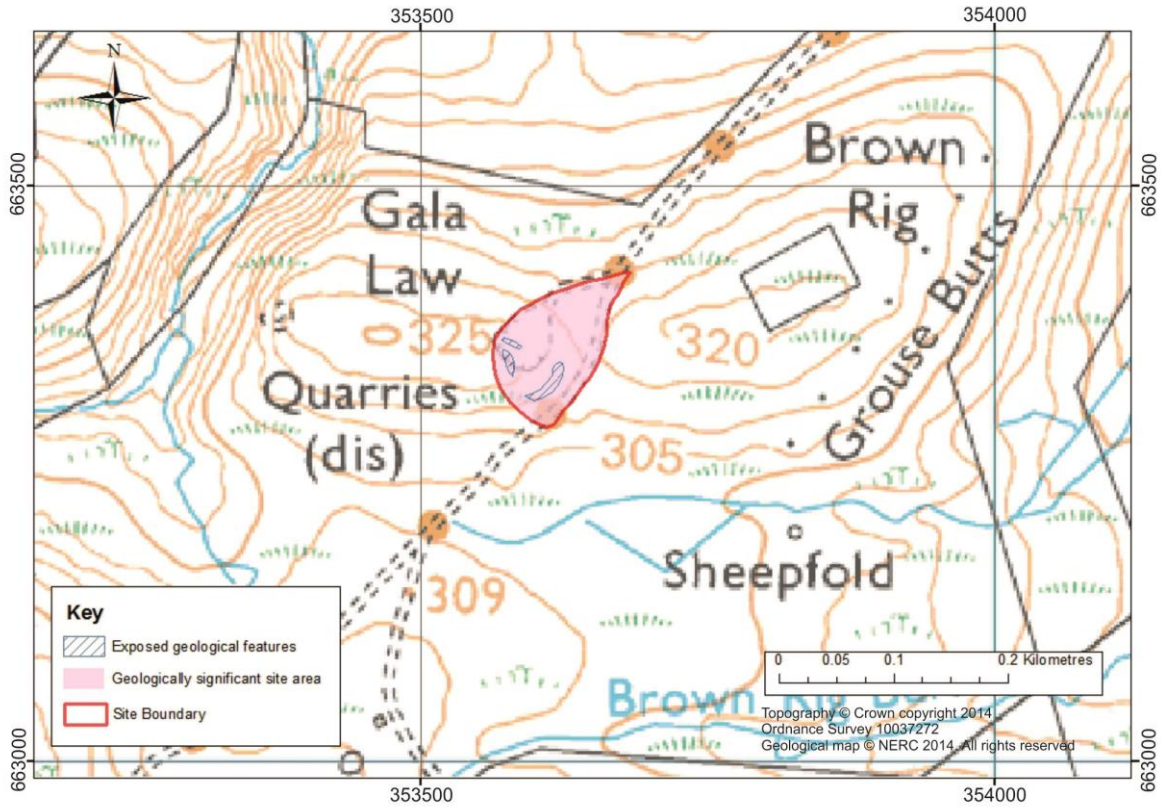


Figure 6: Gala Law Location Map. The site boundary includes key rock exposures, immediate access to the quarry, and viewpoints looking down into the quarry.

Site Description

Background

Gala Law is a small hill approximately 4.5 km south from the village of Gifford accessed by a track leading south-west to Lammer Law. The Silurian rocks underlying Gala Law are exposed in a quarry, in use since at least 1854 for roadstone,

Sedimentary Rocks

The quarry exposes Silurian sedimentary rocks of the Gala Group, deposited in a marine environment as part of a turbidite sequence. The eastern wall of the quarry has been recently worked and provides a 30 m long section, in subvertical, gently folded, thinly-bedded (mm- and cm-scale) alternating brown-weathered siltstone, pale grey and black micaceous mudstone (Photo ELC_1 P1). This sequence represents a distal turbidite deposit, typical of low energy background sedimentation depositing fine layers of sediment following rapid deposition of wackes (high-matrix sandstone) during high-energy turbidity currents (Photo ELC_1 P2). Rare graptolites can be found within the black shale layers (Photo ELC_1 P3), in abundant blocks on the quarry floor. On the western side of the quarry, a 1 m thick rib of massive, red-brown weathered, coarse-grained quartzo-feldspathic greywacke is exposed, representative of a high-energy, channelled turbidite flow (Photo ELC_1 P4). This wacke has been extensively quarried and large blocks of it are piled up on the quarry floor.

Structural Geology

The steeply inclined rocks at this site are typical of the Southern Upland accretionary complex. They have been also been gently folded, with the best examples found in the siltstones and shales in the eastern wall of the quarry. A minor fault is also present here, forming a 10 cm wide brecciated zone cross-cutting siltstone units (Photo ELC_1 P5). Mineralised, slickenlined fracture surfaces are exposed on the rib of greywacke in the west of the quarry, along with reddened iron-stained fractures.

Access and Additional Information

The site can be accessed along the track from the car park for Lammer Law, just at the entrance to Blinkbonny Wood. At the time of the field assessment, fresh rock piles within the quarry indicate that the quarry is still active at a small scale, and therefore care should be taken whilst visiting. The sides of the quarry are not high, but care should be taken when examining faces as any loosened rock is liable to fall, quarried blocks can be examined from piles on the quarry floor away from the quarry walls (Photo ELC_1 P6).

Stratigraphy and Rock Types

Age: Silurian	Group: Gala Group
Rock type: Greywacke, siltstone, mudstone,	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Road access along minor roads heading toward the farmstead of Longyester, and heading south toward Blinkbonny Wood. Parking is available at the entrance to the Blinkbonny Wood.
Safety of access	The site is accessed along a minor road and along a well-marked gravel track within upland terrain.
Safety of exposure	Care should be taken when examining faces within the quarry as the rocks may be loose, and an assessment made of each face before approaching. The bases of rock piles should be avoided. The floor of the quarry is uneven in places and may become locally flooded following rain.
Access	Small-scale quarry operations may impose temporary restrictions on access.
Current condition	The eastern wall in particular is well exposed, with the western wall increasingly covered by vegetation or dumped materials.
Current conflicting	Small-scale active quarry operations.

activities	
Restricting conditions	Quarry operations may impose temporary restrictions on access.
Nature of exposure	Quarry section

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	The Gala Law quarry has been worked historically from at least 1854, and likely even longer in a now disused and overgrown quarry on the western side of Gala Law.
Aesthetic landscape	Gala Law lies at the northern margin of the scenic Lammermuir Hills, gently rolling uplands frequented by walkers. The popular Lammer Law (a SSSI for biodiversity) is accessed via the track adjacent to this site.
History of Earth Sciences	No known association
Economic geology	The quarry was historically worked for roadstone, and is still in small-scale operation today.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary Interest
Lithostratigraphy	Local	Moderately good		X
Sedimentology	Local	Moderately good		X
Igneous/Mineral/ Metamorphic Geology				
Structural Geology	Local	Poor		
Palaeontology	Local	Moderately good		X
Geomorphology				

Site Geoscientific Value

The quarry on Gala Law provides a moderately good section through the Silurian Gala Group. The site has moderately good exposures of a distal turbidite sequence, including graptolite fossils, which are indicative of Silurian deep marine environments. There are also exposures of associated folding and faulting within the sedimentary rocks.

Gala Law quarry provides a moderately good example of Silurian deep marine sedimentology with local stratigraphic significance. It also provides a local example of graptolite fossils, preserved to moderately good quality.

Assessment of Site: Current Site Value

Community	The site is passed daily by walkers climbing Lammer Law.
Education	The site provides a moderately good section through a Silurian turbidite sequence that would provide a good introduction to marine depositional processes and environments, and the relationship between sedimentary strata and graptolite fossils.

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering/erosion, sample/fossil collecting, dumping, likelihood of development
Potential use	The site has teaching potential for Higher/Further education and school education. Use of the site for teaching purposes may be enhanced by an on-site interpretation (such as sign boards at the car park or along the path) or a Geo-trail, along with online information.

Geodiversity Summary

The site comprises a representative section through fossiliferous turbidite sequences typical of the Silurian era. The sedimentary rocks seen here allow interpretation of marine depositional environments, as well as an understanding of organisms that were alive during the Silurian. The Gala Law is easily accessed by a well maintained track, and forms part of a walking trail to the popular Lammer Law. There is potential for developing the geodiversity value of the through on-site or online interpretation, and engagement with local schools.

Site Photos

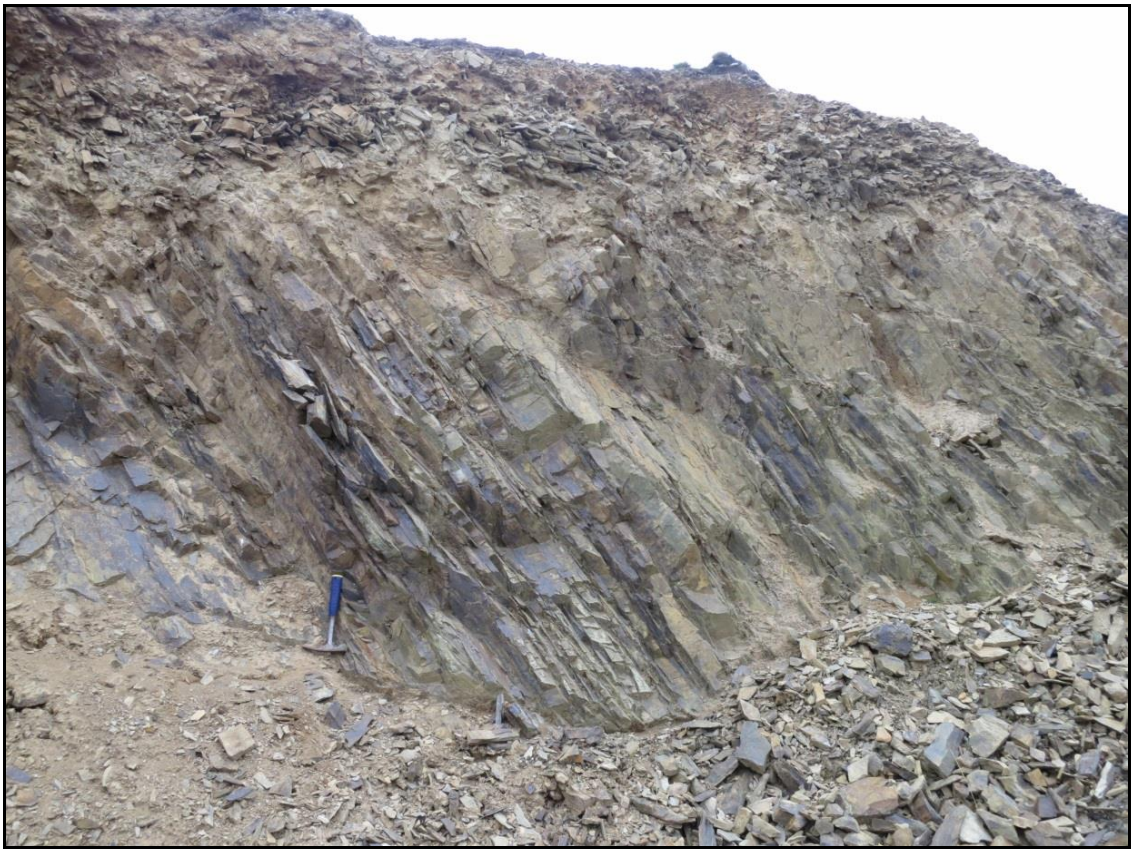


Photo ELC_1 P1: Steeply dipping, thinly bedded siltstones, mudstones and shales exposed in the east wall of the quarry at Gala Law. The thicker units are grey-brown siltstone, with thinner black shale and pale grey micaceous mudstone between. These sequences represent low-density submarine turbidity current deposits, resulting from low-concentration flows transporting mainly silt- and clay-sized material. These fine-grained sediments would have been deposited by suspension fallout and traction, following a period of high flow velocity and rapid deposition of the initial coarse-grained sandy turbidite. Photo looking toward the south-east. © BGS, NERC.

Photo ELC_1 P2: Detail of very fine (mm-scale) laminations within the siltstone, mudstone and shale sequence exposed in the east wall of the quarry. These sediments were laid down in submarine fan systems adjacent to the Laurentian continental margin. Siltstone layers are yellow-brown, mudstone layers are pale-grey and shale layers are black. © BGS, NERC.

Photo ELC_1 P3: Hand specimen from the site reveals a black shale layer containing abundant graptolite fossils. Graptolites are one of the characteristic fossils used to help define the stratigraphy of the Ordovician and Silurian successions, and have been used to define 'biozones' throughout the strata, aiding geologists in dating the sequence. Graptolites, marine colonial organisms, lived from the Upper Cambrian to the Lower Carboniferous. © BGS, NERC.

Photo ELC_1 P4: A 1m thick rib of brown-red greywacke (coarse-grained, poorly-sorted sandstone characterised by quartz, feldspar and lithic clasts forming more than 15% of the rock) is exposed on the western wall of the quarry. The greywacke was deposited as part of a turbidity current during Silurian times, the principal depositional agent in the submarine fan systems dominating the region at the time. Such coarse-grained sediments within turbidite sequences are representative of high flow velocities and rapid rates of deposition during the onset of a turbidity current, which can be strong enough to scour submarine canyons into unconsolidated deep sea sediments. Photo looking toward the west. © BGS, NERC.

Photo ELC_1 P5: A 10cm wide fault zone is exposed at the north end of the east wall, composed chiefly of brecciated clasts of the surrounding siltstone. Photo taken looking west. © BGS, NERC.

Photo ELC_1 P6: Typical view of the eastern quarry wall, exposing sequences of siltstones, mudstones and shale. Quarry activity has left clean fresh faces to examine, as well as large rock piles on the floor of the quarry, such as the one in the right of the photo. These rock piles have extensive hand specimens to examine without sampling from the quarry wall itself. Photo looking south. © BGS, NERC.

ELC_2: Burn Hope ('Fairy Glen')

Site Information

Location and Summary Description:

The site is situated 9 km south-east of Dunbar, within an upland area comprising the north-eastern margin of the Lammermuir Hills, 4 km west of the small hamlet of Oldhamstocks. Burn Hope lies immediately to the west of the Aikengall Windfarm. The site itself is a ~450 m long section along a narrow stream gorge, centred around 'Fairy Castle' and is known locally as 'Fairy Glen'. Low cliffs along this scenic gorge expose conglomerates and sandstones of the Lower Devonian Great Conglomerate Formation.

National Grid Reference: Mid-point: 370105, 669941 West end: 369824, 669951 East end: 370284, 669947	**Site type**: • Natural Section • Natural Exposure • Natural Landform
Site ownership: Not known	Current use: Open Country
Field surveyors: Hugh Barron and Rachael Ellen	Current geological designations: None
Date visited: 25th September 2014	Other designations: Lammermuir Deans Biological SSSI; part of East Lammermuir Deans Nature Reserve, within Lammerlaw AGLV, Innerwick Ancient Woodland Site

Site Map

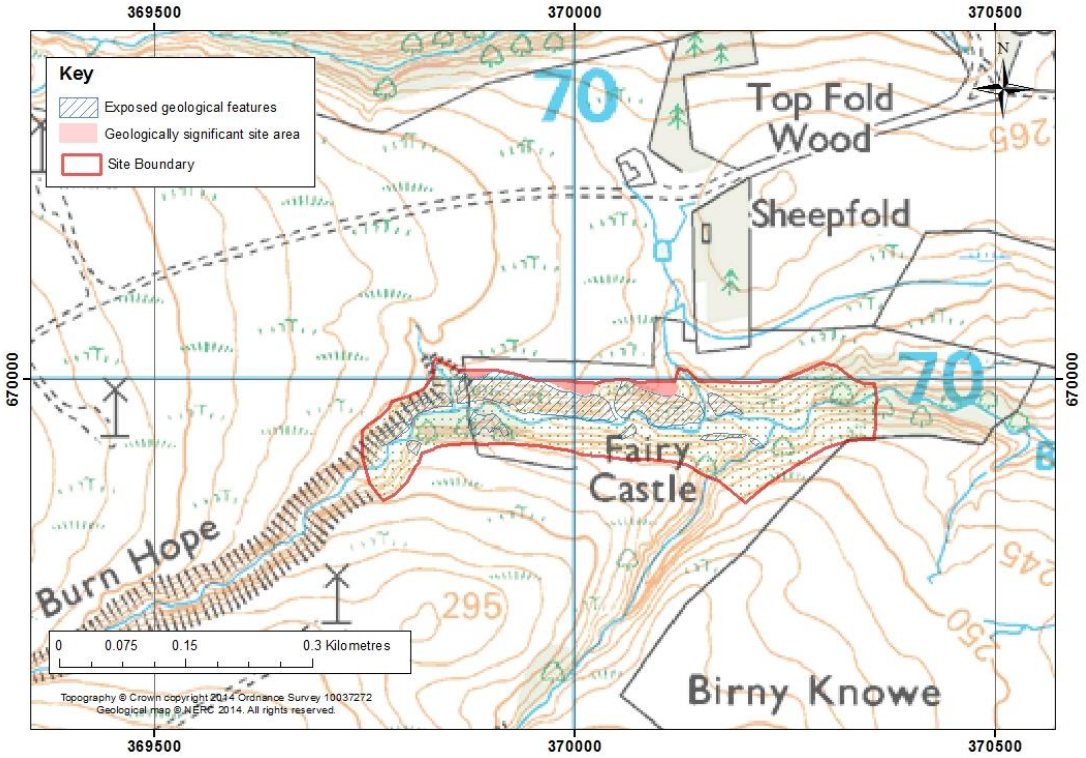


Figure 7: Burn Hope ('Fairy Glen') Location Map. The exact area of bedrock exposure is likely to vary over time due to erosion and changes in vegetation. The landform area covers the glacial meltwater channel along which the bedrock at the site is exposed, and is therefore included within the Site Boundary. Northern parts of the site have been designated geologically significant as they provide good viewpoints across the site from the rim of the gully.

Site Description

Background and site area

The site borders that of the Aikengall Community Windfarm, which lies immediately to the west. An extension to this wind farm was granted in 2013, and at the time of site visit, construction warnings were in place along the access road, which may affect access to the site in the short term. The site comprises a naturally formed glacial meltwater channel.

Sedimentary Rocks

A 20 m section through the Great Conglomerate Formation (Lower Devonian in age) is excellently exposed at the site, particularly on the south-facing cliffs. The cliffs are composed mostly of loosely bedded red-brown conglomerates and subordinate sandstones formed from sediment deposited by high energy streams in a series of alluvial fans at the margin of a mountain range (Photo ELC_2 P1). The conglomerate beds are up to 4 m thick, containing cobble to boulder grade (<45 cm in size) clasts of volcanic rock, quartzite and greywacke (Photo ELC_2 P2). The cobble grade clasts (<64 mm) are typically sub-rounded, elongate and flat, and display a weak to well-developed imbrication in parts of the section indicating that they were deposited by rivers flowing to the east-south-east (Photo ELC_2 P3). The conglomerate is interbedded with thin red sandstones and green, thinly laminated silty sandstones up to 5 cm thick, with rare desiccation cracks indicating periodic drying out of the wet sediment occurred during deposition.

Volcanic Rocks

A 50 cm wide basalt dyke (the so-called 'Fairy Castle') with sparse vesicles is exposed at the site (Photo ELC_2 P4), cropping out as a conspicuous rock wall in the east of the site. The dyke has baked and hardened the adjacent conglomerate (Photo ELC_2 P5).

Quaternary Deposits and Landforms

There are good examples of small talus fans forming from natural erosion of the conglomerate cliffs (Photo ELC_2 P6). The small fans are comparable in morphology to the much larger fans from which the Great Conglomerate originated. Imbricated river gravels in the bed of Burn Hope also provide a modern analogue for the development of flow-alignment in fluvial sediments that may be compared with the imbrication of clasts in the Great Conglomerate. Natural erosion by glacial meltwater has formed a deep gorge cutting the sequence. Post-glacial weathering of the partially carbonate-cemented conglomerate has resulted in a 'badlands' landscape, featuring boulder capped residual pillars and picturesque isolated rock stacks. The scenic nature of these pillars and stacks has historically earned the exposure the name of 'Fairy Glen' and 'Fairy Castle' (Photo ELC_2 P7).

Access and Additional Information

The site is accessed by a minor road and a short stretch of rough gravelled track. Car parking (is available off-road adjacent to the Aikengall Windfarm substation. Burn Hope is accessed south of the car park, via a small bridge, leading onto a path over open moorland. The descent into the valley of Burn Hope is steep and may be difficult when wet; care should be taken when accessing the site. Although the cliffs are not high, active erosion is ongoing with small clasts falling out of the conglomerate on a regular basis, forming small talus cones at the base of the cliffs. The basalt dyke is accessed by crossing a fence with wooden slats at the confluence of Bladdering Cleugh with Burn Hope.

Stratigraphy and Rock Types

Age: Early Devonian	Group: Reston Group	Formation: Great Conglomerate Formation
Rock type: Conglomerate and subordinate sandstone, interbedded		
Age: Carboniferous to Early Permian	Suite: Midland Valley Carboniferous to Early Permian Alkaline Basic Dyke Suite	
Rock type: Basalt		

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Road access past Thurston Mains to Wester Aikengall, then along to the Aikengall Windfarm substation. Cars can be parked off-road here, leaving access to the substation clear.
Safety of access	A small path leads from the parking area across a small bridge, through moorland to a laddered stile crossing a fence. This leads to a view point over Burn Hope, the base of which can be accessed with care down some steep but naturally stepped ground. Care should be taken on surfaces with loose material. Stout footwear is recommended. The site can get very windy and therefore care should be taken whilst walking along the top of the cliffs to access the floor of the gorge.
Safety of exposure	The low cliffs are continually eroding, particularly in high winds and rain, and so care should be exercised at the base of the cliffs.
Access	Access by footpath and open country. The extension of the Aikengall Windfarm may impose temporary restrictions on road and pedestrian access.
Current condition	The rocks are well exposed.
Current conflicting activities	Extension of Aikengall Windfarm may impose on road access in the short term.
Restricting conditions	Activities related to Aikengall Windfarm may impose restrictions on access.
Nature of exposure	Gorge cut by fluvial and glaciofluvial processes, with natural cliff exposures.

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	No known association
Aesthetic landscape	Picturesque, peaceful stream gorge in upland region of Lammermuir Hills.
History of Earth Sciences	No known association
Economic geology	No known association

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary Interest
Lithostratigraphy	Regional	Good	Browne et al., 2002; Davies et al., 1986; Stone et al., 2012	X
Sedimentology	Local	Good	Browne et al., 2002; Davies et al., 1986; Stone et al., 2012	
Igneous/Mineral/ Metamorphic Geology	Local	Moderately good		
Structural Geology				
Palaeontology				
Geomorphology	National	Excellent	Davies et al., 1986;	X

Site Geoscientific Value

The site comprises a sequence of conglomerates and subordinate sandstones, allowing interpretation of the depositional environment during the Lower Devonian. Whilst numerous outcrops of Lower Devonian conglomerates exist across Scotland, few belong to the Great Conglomerate Formation. The rocks are also unusually weathered to a 'badlands' topography, a weathering phenomenon relatively rare in the UK.

Burn Hope provides an excellent example of 'badlands' geomorphology with national significance. It also provides a good example of Lower Devonian fluvial sedimentology with regional stratigraphic significance.

Assessment of Site: Current site usage

Community	Due to its relative remoteness and hidden nature, the site is likely rarely visited by the public, although it forms part of the East Lammermuir Deans Nature Reserve.
Education	The site presents the best natural exposure of the Great Conglomerate Formation in East Lothian. This site may be a good locality for educational fieldwork relating to the Lower Devonian in Scotland. A leaflet with a map of a geo-trail detailing the geology and geomorphology would complement the Nature Reserve well. An on-site interpretation board overlooking the site from the viewpoint beyond the stile may also be appropriate.

Assessment of Site: Fragility and potential use of the site

Fragility	Geohazard, weathering/erosion, natural overgrowth.
Potential use	Research, higher/further education, school education, on-site interpretation

Geodiversity Summary

The site comprises good exposures of Devonian sedimentary rocks in a unique geomorphological setting. The site area is accessible, but its rural location means that it is likely to appeal to local interest and educational groups. The geodiversity value of the site may be enhanced by the provision of additional information on the geology on site or on-line that is suitable for teaching purposes.

Site Photos

Photo ELC_2 P1: Loosely bedded, massive, slightly imbricated conglomerate beds dominate the 10 m high cliffs of the Burn Hope site. Clast sizes vary across the site – in this photo, clasts up to 45 cm are found, whereas to the east of the site smaller clasts are seen. The different sizes of clasts is indicative of differing energies in the fluvial-terrestrial environment that supplied this sediment, where large rivers and alluvial fans drained broadly towards the south-west during Lower Devonian times. Photo looking north west © BGS, NERC.

Photo ELC_2 P2: Detail of the matrix-supported nature of the conglomerate. Note most of the smaller clasts are flat and elongate. The reddened nature of the rocks is indicative of deposition in a semi-arid environment. © BGS, NERC.

Photo ELC_2 P3: Imbrication of clasts within the conglomerate can be seen just below the camera case, orientated top left to bottom right with respect to the photo. The imbrication here is truncated by a thin (5 cm) layer of green silty sandstone. © BGS, NERC.

Photo ELC_2 P4: The basalt dyke cutting the sequence at Burn Hope contains small vesicles and a set of fractures parallel to the edge of the dyke. © BGS, NERC.

Photo ELC_2 P5: The dyke forms a proud standing rock wall ('Fairy Castle') at the southern end of the eastern margin of the site. The camera case here rests on the dyke itself, and the higher rock to the left of the dyke is the hardened, baked conglomerate. Photo looking north. © BGS, NERC.

Photo ELC_2 P6: Talus fans are commonly found forming at the base of these 20 m high cliffs, and are actively, but slowly, growing. The talus fans mimick, albeit on a much smaller scale, the processes that would have formed the Great Conglomerate during the Lower Devonian, i.e. erosion of mountains and deposition in alluvial fans. Photo looking north, cliff height around 20 m. © BGS, NERC.

Photo ELC_2 P7: The gorge was formed by fluvial processes, which as well as leaving spectacular rock cliffs, has also left conspicuous rock spires. These erosional features are conical columns usually capped by a boulder (conglomerate clast) that shields the underlying softer rock from erosion. © BGS, NERC.

ELC_3: Gin Head (near Tantallon Castle)

Site Information

Location and Summary Description:

Gin Head is a rocky peninsula c. 300 m to the north-west of Tantallon Castle. The rocks exposed in the rock platform at the base of the cliffs are of primary interest: however, access to the site is difficult and dependent on the tides. Fossils, including the jawbone of a Lower Carboniferous tetrapod, ostracods, lungfish toothplates and wood, have been found historically at the site, making it extremely important for understanding Lower Carboniferous fauna.

National Grid Reference: Mid-point: 359439, 685331	**Site type**: • Natural section • Natural exposure
Site ownership: unknown	Current use: Open country
Field surveyors: Rachael Ellen, David Millward	Current geological designations: Firth of Forth SSSI, GCR (Quaternary and Coastal)
Date visited: 16th September 2014	Other designations: within North Berwick – Dunbar AGLV, Firth of Forth Ramsar

Site Map

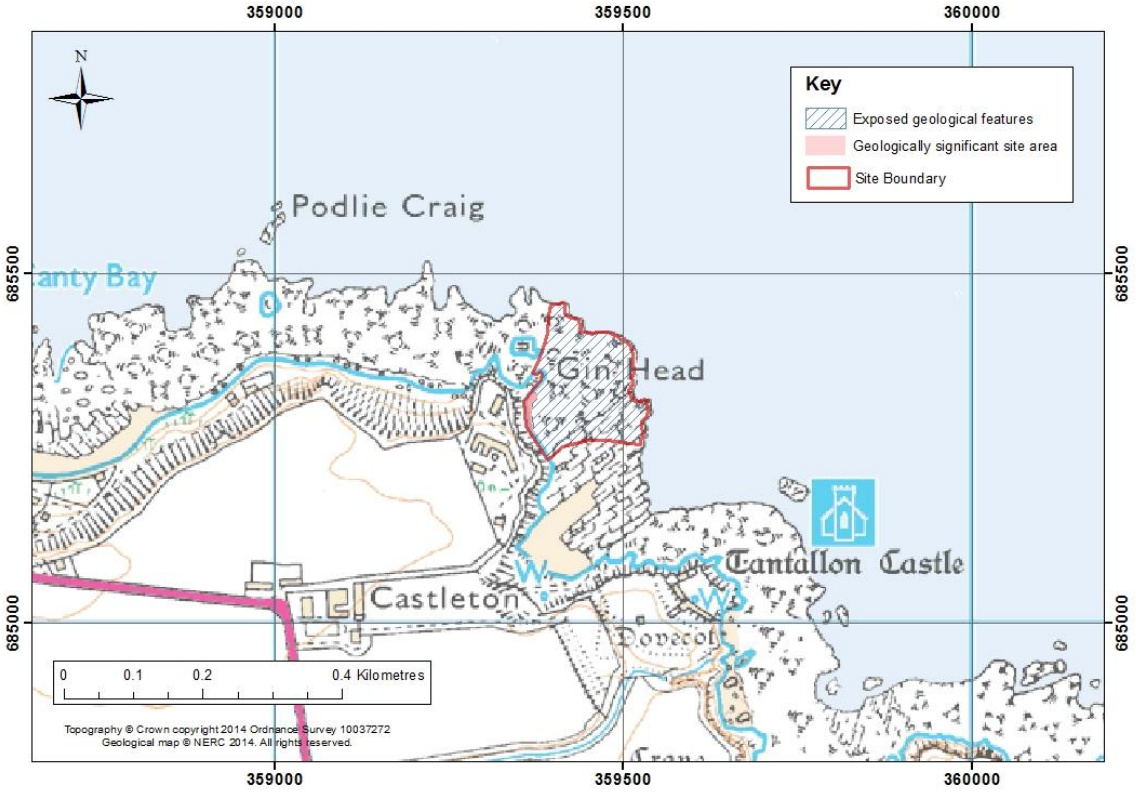


Figure 8: Gin Head (near Tantallon Castle) Location Map. The site boundary has been drawn to include all of the Ballagan Formation bedrock exposure at Gin Head, as well as the intertidal beach at the west of the site. The beach is mapped here as a geologically significant site area, as boulders containing fragments of tetrapods and other Lower Carboniferous fossils have been found here in recent times.

Site Description

Background

Gin Head lies 4 km to the east of North Berwick, along an uneven, rocky, tidal coastline. The lower jawbone of a tetrapod was discovered within sedimentary rocks of the Ballagan Formation here in 1977. The time-span from the end of the Devonian to the early Carboniferous represents an important era in the evolution of tetrapods (i.e. limbed vertebrates). During this 20 million year period, known as 'Romer's Gap', tetrapods evolved from aquatic, fish-like creatures into amphibian-like terrestrial forms. Vertebrate fossils had been previously unknown world-wide from this period. However, an increasing number of vertebrate fossils are being found for the first time from sites in south-eastern Scotland from the Ballagan Formation. This area is thus of international significance in the understanding of this critical adaptation in tetrapod evolution from aquatic to terrestrial environments, and is one of only two such areas in the world at present where this can be studied (the other is in Nova Scotia, Canada). The tetrapod fossils are being investigated by the TW:eed Project (a scientific research collaboration between academic institutes and partners, including the BGS).

Sedimentary Rocks

The sedimentary rocks of the uppermost part of the Ballagan Formation are exposed at this site and consist mostly of a fluvial pink-white, medium-grained sandstone with subordinate mica-rich siltstone beds. These rocks contain a range of sedimentary structures; most notably, striking cross-bedding (ELC_3 P1), erosional channel sand bodies, desiccation cracks within rare mudstones, and ripples within mudstones and siltstones (ELC_3 P2). The strata include a fossiliferous limestone-conglomerate which has yielded tetrapod remains. Whilst this unit was not found in situ at time of site visit, boulders of it were identified near the high tide mark. The fossiliferous rock is composed of clasts of mudstone and sandstone in a carbonate matrix, along with abundant ostracods, bivalves and rarer fossilised wood, gyrocanth spines, lobe-fin fish scales and lungfish toothplates. This rock is interpreted to have been deposited as an accumulation of rock clasts, organic and animal remains at the bottom of a shallow pool set in a fluvial environment.

Structural Geology

Excellent examples of deformation bands cutting the sandstones are found across the site, creating minor (cm-scale) displacements across the sequence (ELC_3 P3). Larger faults are also present, conspicuous by linear absences of rock across the platform. Some of the smaller fault planes are filled with a clast-supported breccia, containing angular fragments of the surrounding sandstone: it is possible these represent cryptic vents where gas streaming along a fracture has deformed the rock relatively in-situ, rather than related to tectonic deformation.

Access and Additional Information

The site is accessed only by a rough traverse along slippery intertidal rocks. The site is cut off by the tide and so knowledge of tide times prior to visit is essential. Access to the west is achieved by walking along the A198 (there are no pavements and care should be taken on the road) toward the private road leading to Canty Bay residential houses. The private road leads downhill until a sharp left hand bend, where the road can be exited to the right, for a footpath heading eastward. The path eventually dies out and access by walking along the shingle is possible until the Gin Head promontory. At this point access is restricted to low tide.

Stratigraphy and Rock Types

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

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Park either at Tantallon Castle, or with permission, at the farmstead at Castleton.
Safety of access	This site is not easily accessible. It must be approached from the west along an intertidal slippery rocky foreshore. Extreme care should be taken when accessing the site, and appropriate footwear worn, and tide tables

	checked and adhered to. Care should be taken if approaching the site via the A198 – this can be a very busy road and there are no pavements.
Safety of exposure	The rock exposure itself is an intertidal rock platform, and as such can be slippery underfoot and have deep rock pools. As with all coastal sites, stout footwear should be worn and care taken. There are steep cliffs with loose material. Hard helmets are recommended if working close to the cliff.
Access	Access along the shore and by coastal footpaths.
Current condition	The rocks are generally clean from barnacles and seaweed in the upper parts of the exposure, but generally covered nearer the low tide mark.
Current conflicting activities	None.
Restricting conditions	Weather and tide: access and exposure are located within the intertidal zone, and access can be very easily cut off if due attention is not paid
Nature of exposure	Rocky foreshore

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	A decommissioned second world war radar station is situated on the cliffs above the site. The deception and jamming operations tested here were key to the success of the D-Day landings in Normandy on 6th June 1944. Tantallon Castle lies to the south-east.
Aesthetic landscape	Views toward Bass Rock and Tantallon Castle
History of Earth Sciences	Recorded find of tetrapod limb in 1977.
Economic geology	No known association

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology	Local	Good		
Igneous/Mineral/ Metamorphic Geology				
Structural Geology	Local	Excellent		
Palaeontology	International	Excellent	Day (1928)	X
Geomorphology				

Site Geoscientific Value

The site displays a good range of sedimentary rocks and associated structures within Lower Carboniferous strata. The rocks of the Ballagan Formation exposed at this site and at several others in south-eastern Scotland are one of only two areas known in the world where the fossil record within Romer's Gap can be studied to understand a crucial period of Earth's History. This site is therefore of international significance.

Gin Head provides a good example of sedimentary rock structures within Lower Carboniferous rocks, with international palaeontological significance.

Assessment of Site: Current site usage	
Community	The site itself is little visited. It is likely only visitors with specialised interest would visit.
Education	Due to the site's relative inaccessibility, the site would not be recommended for school visits, on-site interpretation nor geo-trails. However, because of its international significance the site should be noted for its research and higher/further education potential.

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering/erosion; sample/fossil collecting; development of coastal defence may affect the geodiversity.
Potential use	Research, higher/further education

Geodiversity Summary

The site provides good examples of sedimentary rocks originally deposited within a fluvial environment during the early Carboniferous. Dry periods forming small, shallow pools surrounding the fluvial environment preserved a selection of vegetation and animals from the Lower Carboniferous, fossilised within the rock record. The site is of international significance due to recorded findings of tetrapods from this site, which have previously not been found in rocks of this age across the world. The site itself is difficult to access and as such is not suitable for any large number of visitors, but should be given geodiversity status due to its international significance, research, higher and further education potential.

Site Photos

Photo ELC_3 P1: Trough cross-bedding developed within fluvial sandstones of the Ballagan Formation. Note the sub-horizontal bedding in the foreground is truncated by the cross-bedded layer, suggesting the cross-bedding developed within a river channel that actively eroded earlier deposits. Photo looking toward the north-east. © BGS, NERC.

Photo ELC_3 P2: Ripple lamination within sandstone and siltstone lithologies across the site are common. This photo shows a cross-section through a rippled sequence of siltstones. © BGS, NERC.

Photo ELC_3 P3: Deformation bands (linear bands produced by faulting, composed of crushed quartz grains with a component of displacement) cross cut sedimentary layering across much of the site. These bands are associated with cm-scale displacements, and deformation (folding or buckling) of the sedimentary layering. © BGS, NERC.

ELC_4: Dunbar Shore, Dunbar

Site Information

Location and Summary Description:
3 to 4 km section of coastline, located to the west, north and east of the town of Dunbar. The site displays a variety of upper Devonian and lower Carboniferous geological strata, structures and intrusions, and coastal geomorphological features. There are also geological links to the social and economic history of the town and the built heritage.

National Grid Reference: Mid-point: 368100,679300 North-west end: 366200,679400 South-east end: 369300,678500	**Site type**: • Natural section / exposure • Natural landform • Natural View
Site ownership: Crown	Current use: Open country
Field surveyors: Sarah Arkley, Katie Whitbread, Eileen Callaghan & Rachael Ellen	Current geological designations: 2 GCR sites (GCR ID: 182 and 2301), part of the Firth of Forth SSSI
Date visited: 26th March, 2014	Other designations: Firth of Forth SPA and Ramsar, Dunbar Conservation Area and John Muir Country Park, North Berwick – Dunbar AGLV

Site Map

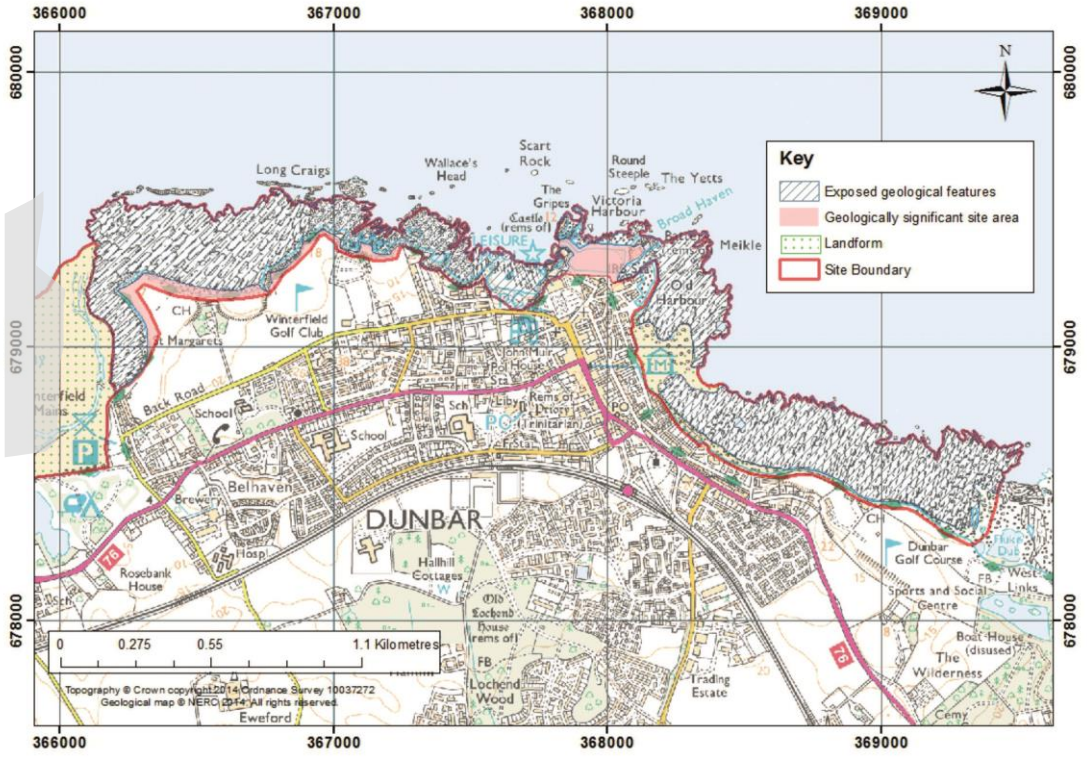


Figure 9: Dunbar Shore Location Map. The site comprises rock exposures along the shore platform and coastal landforms including shore platforms, raised beach, and areas of beach in the immediate vicinity of the main rock outcrops**,** The exact area of bedrock exposure (blue hatched areas) is likely to vary in time due to changes in the beach morphology. Geologically significant areas also included within the site boundary are important view or access points to the rock exposures. The adjacent geomorphological Tyne Estuary & Belhaven Bay Site (ELC_28) is shown for reference (transparent grey polygon).

Site Description

Background

The town of Dunbar is located on a headland jutting out into the North Sea, in an elevated position with high sea-cliffs and a rocky foreshore. The coastal landscape reflects the underlying geology; the hard igneous rocks which lie beneath the town were more resistant to erosion during the last ice age than the softer sedimentary rocks to the north and south. The siting of this strategically important east coast town must in part be due to the defensive qualities offered by the form of the coastline; the castle and battery were built on rocky promontories, almost surrounded by the sea, and defended the town and its occupants over centuries of invasions; the large solid harbours are cut into bedrock and protected fleets of boats which brought trade, industry and prosperity to the town. Local industries exploited the natural geological resources; including clay to make bricks and tiles at Seafield, near Belhaven; igneous rocks were extracted from a quarry at Knockenhair, western Dunbar; red sandstone removed during the construction of the harbours may have been used as building stone in the harbour walls; and golf is thought to have been played on the raised beaches for almost 400 years.

The extent of the site is from Belhaven Bay to the Dunbar Golf Course, chosen as it includes extensive exposures of Devonian and Carboniferous sedimentary rocks, a selection of Carboniferous volcanic intrusions, a variety of structural features and a wide range of coastal and glacial Quaternary landforms.

Sedimentary Rocks

Devonian sedimentary rocks are well-exposed in the eastern part of the site, dominantly on the intertidal shore platform. The easterly dipping sequence contains bedded red and red-brown sandstones, with siltstones, silty mudstones and cornstones, and displays a range of sedimentary structures, including; channels, cross-bedding, reduction spots and ripples (Photo ELC_4 P1). The sediments are thought to have been deposited in a partly fluviatile (river) and partly lacustrine (lake) environment.

Thick bedded sandstone belonging to the Kinnesswood Formation is exposed in cliffs near the coastal path north of Dunbar (west of the leisure centre). The sandstone is strongly cross-bedded and there are accumulations of mudstone rip-up clasts at the base of some beds; these were deposited by large rivers. In the upper part of the sequence seen are developed nodular concretions, some of which clearly developed around plant roots (referred to as rhizocretions). These cornstone beds are interpreted as fossil calcrete soils which developed in an arid or semi-arid climate (Photo ELC_4 P2).

The Lower Carboniferous sedimentary rocks, exposed in the western part of the site (Belhaven Bay), belong to the upper part of the Ballagan Formation and are composed of thin cementstones (dolomitic limestones) and mudstones, interbedded with sandstone and siltstone (Photo ELC_4 P3 & 4). The sediments are thought to have been deposited in fluvial and shallow lagoonal environments and display sedimentary structures such as ripples and trace fossils (Photo ELC_4 P5). The presence of surfaces with fossil mudcracks indicates a terrestrial environment. The strata appear gently folded and faulted where exposed on the intertidal shore platform near Belhaven Point, and has been intruded by a number of dykes of various compositions.

Volcanic Rocks

The early Carboniferous volcanic vents and intrusions which penetrated the sedimentary rocks, and for which the site is perhaps best known, are superbly exposed at various places along the intertidal shore platform and in cliff sections. The volcanic vents, starting at Belhaven Bay are named the Belhaven Point, Parade, Dove Rock, Castle Rocks, Old Harbour, Coastguard Station and Kirk Hill vents, which fed the early Carboniferous volcanoes. The vent material consists mainly of lithified volcanic ash (tuffs) (Photo ELC_4 P8 & 9), with some breccias, and basaltic intrusions. Bedded, poorly sorted pyroclastic rocks, including tuff and breccia, exposed in the cliffs to the west of the town show characteristics that are typical of volcanic eruptions that occur when magma comes into contact with large volumes of water (phreatomagmatic); these features include non-vesicular fragments, abrupt bed-by-bed changes in grain size and some fine examples of volcanic bomb sags. These bedded pyroclastic rocks were probably remnants of volcanic cones. A description of the early Carboniferous vents present along the site can be found in the Lothian Geology Excursion Guide (McAdam & Clarkson, 1986: pg119-132)

The strata are latterly traversed by a group of ENE-WSW trending quartz-dolerite dykes, best seen at Belhaven Bay (Photo ELC_4 P6) and also form the offshore skerries north of Dunbar. Basaltic intrusions are additionally present within the site; the best example forms the foundations of The Battery and displays superb columnar jointing (Photo ELC_4 P7).

Quaternary Deposits and Landforms

Excellent Quaternary features and deposits are also present at the Dunbar site. Cross-sections through Quaternary raised beach deposits are exposed along the westward facing coast at Belhaven Bay, where gently dipping deposits of shingle, sand and shells are found overlying a rock platform cut into the Ballagan Formation (Photo ELC_4 P10). Along the coast various erosional landforms can be seen, including raised beaches, intertidal shore platforms, stacks, cliffs, caves, offshore skerries and an arch (Photo ELC_4 P11). Two Geological Conservation Review sites (GCR ID 182 and 2301) are located along the Dunbar Shore coastline: one which describes four distinct shore platforms, of different ages, that have been particularly well-preserved in the vicinity of Dunbar (ranging in altitude from 25m above sea level to 11m below present sea level); and one which describes the excellent range of rocky coastal landforms, representative of erosional coastal features found along the east coast of Scotland. Both GCR sites are important in terms of Quaternary reconstruction, the interpretation of former sea-level changes and the erosional processes characteristic of rock-coast development in south-east Scotland.

Structural Geology

There are features throughout the entire site which show good examples of structural geology and its effect on fluid migration within rocks. Within the Devonian and Carboniferous strata, groundwater along local fractures has bleached the immediately surrounding rock, changing its colour from red to white (Photo ELC_4 P12). Faults and fractures cross cut the sedimentary strata, forming natural linear gullies within the foreshore (Photo ELC_4 P13). There are also local examples of deformation bands (fractures which have seen some displacement and quartz grain crushing) within the sedimentary strata. In other areas, dendritic growths of iron leaching out of fractures are seen in the Ballagan Formation. On a larger scale, there are faults displacing the sequences with local folds forming anticlines and synclines, particularly within the Ballagan Formation.

Access and Additional Information

Access and views of the coastline at Dunbar is very good, greatly aided by the presence of coastal footpaths, particularly the John Muir Way. At the western end of the site, the John Muir Way meanders along the high cliff tops providing excellent views of the geology and coastal erosion features on the shore below, and of views further afield towards the Bass Rock and the islands lying within the Firth of Forth. At the eastern end the path winds its way along the raised beach and provides easy access to the foreshore.

Along the sea front, and particularly around the Victoria and Cromwell harbours, there are a significant number of information boards describing and illustrating the local history and wildlife of the area. However, there is little mention of the local geology or landscape, despite it being an important factor in the siting and building of Dunbar Castle, the Battery and the two harbours; and in how the local area has been shaped during the Ice Age. The information described in these few pages should show that there is great scope for introducing geology to those that visit the Dunbar area, particularly with the town's association to John Muir, who campaigned for the preservation of natural environments through his work as an environmentalist, geologist and botanist.

Stratigraphy and Rock Types	
Age: Devono- Carboniferous	Formation: Upper Old Red Sandstone and Kinnesswood Formation
Rock type: Sandstones, siltstones and mudstones	
Age: Lower Carboniferous	Formation: Ballagan Formation
Rock type: Sandstone, siltstone and dolomitic limestone (cementstone)	
Age: Lower Carboniferous	Formation: Southern Scotland Dinantian Plugs and Vents Suite
Rock type: Tuff and breccia	
Age: Upper Carboniferous	Formation: Central Scotland Late Carboniferous Tholeiitic Dyke Swarm
Rock type: Quartz-microgabbro (quartz-dolerite)	
Age: Carboniferous to Early Permian	Formation: Midland Valley Carboniferous to Early Permian Alkaline Basic Dyke Suite
Rock type: Microgabbro (dolerite)	

Age: Quaternary	Formation: Raised marine deposits of Flandrian Age
Rock type: Sand and gravel with shells	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Good access from Belhaven Bay car park and there are various places to park with access to the coast from Dunbar town centre. The John Muir Way footpath follows the coastline around Dunbar and allows excellent access to and/or views of most of the site.
Safety of access	Well-trodden footpaths generally provide good, safe access for visitors to look at outcrops and landforms along most of the site, but care should be taken if leaving the main paths. Access to the shore platform is restricted north of Dunbar where there are high vertical cliffs. All visitors should be aware of the tide times when planning a visit, as many of the exposures are only visible at low tide, and due to the high cliffs an unwary visitor could be cut off from their planned exit route.
Safety of exposure	Although the majority of the cliffs appear stable, care should always be taken when beneath cliffs of any height and visitors should not stand beneath any overhanging areas. The rocky intertidal areas have an uneven surface, and are in places boulder-strewn and often slippery with algal growth. Stout footwear is recommended. The site may feel very exposed under certain weather conditions, 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 park.
Current condition	Rock exposures are generally clean and free of vegetation or litter, due to washing from tides, but the intertidal zones can be covered in seaweed or barnacles obscuring small-scale geological features.
Current conflicting activities	Two golf courses are located adjacent to the site and may restrict access to parts of the site, but paths are generally present along their shore edge or access can be gained by walking along the foreshore.
Restricting conditions	Tide: many of the geological exposures are located in the intertidal range and therefore covered at high tide.
Nature of exposure	Vertical cliff sections, intertidal & beach exposures and coastal landforms.

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	Dunbar Castle (dating from around the13th century), The Battery (built in 1781), Dunbar's Harbours (Cromwell and Victoria) and McArthur's Store may all have used local stone in their construction. Dunbar is the birthplace of John Muir (naturalist and early advocate of the preservation of the natural environment) and the Town House Museum in Dunbar (displays a variety of local history).
Aesthetic landscape	Coastal landscape
History of Earth Sciences	John Muir's birthplace
Economic geology	Information from the John Muir Birthplace Fact Sheet, Number 3.12-Dunbar Geology: "A lot of the stone was exploited in Muir's time. The Castle Rock was quarried for walls and buildings as a new harbour was created. Marls and mudstones to the west were burnt for cement and deposits of clay at Belhaven were worked for brick and tile manufacture. To the east many tons of fossiliferous limestones and shales were burnt every year for lime (used as mortar and field dressing)."

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy	Regional	Good		X
Sedimentology	Regional	Excellent		X
Igneous/Mineral/ Metamorphic Geology	Regional	Excellent		X
Structural Geology	Local	Good		
Palaeontology				
Geomorphology	Regional	Excellent	May and Hansom, 2003; Gordon and Sutherland, 1993	X

Site Geoscientific Value

The shore section at Dunbar has excellent exposures of both volcanic (particularly phreatomagmatic deposits) and sedimentological (particularly paleosols) features, indicative of Carboniferous volcanic and terrestrial (including fluvial) environments. There are also excellent exposures of raised beaches and their relationship with the underlying rocks.

Dunbar Shore provides excellent, regionally significant examples of Carboniferous volcanic rocks, fossil calcrete paleosols and of their litho-stratigraphical relationships. It also provides excellent examples of Quaternary landforms with regional significance.

Assessment of Site: Current site usage

Community	The attractive town, local history, scenic coastline and easy access means both locals and visitors from further afield are regularly passing through the site. The two golf courses located on raised beaches adjacent to the site additionally draws people to the area.
Education	The site displays a wide variety of features suitable for educational visits. Most of the site has good safe accessibility and would be suitable for larger groups. The site has potential for geosciences research, and teaching potential for Higher/Further and School level education**.** Use of the site for teaching purposes may be enhanced by leaflets or online information. Members of the general public would benefit from on-site interpretation such as sign boards or a Geo-trail.

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion; development of coastal defences may affect the geodiversity
Potential use	Research, Higher/Further Education, School Education, On-site interpretation, On-site geotrail, Multidisciplinary

Geodiversity Summary

An outstanding site containing a wide variety of good quality geological and geomorphological features. This site exposes a long, semi-continuous section through typical upper Devonian to lower Carboniferous sedimentary strata. The strata display a variety of characteristic sedimentary structures which allow an interpretation of the environment at the time of deposition, with an excellent assortment of early Carboniferous volcanic intrusions (particularly vents and dykes) and of pyroclastic rocks, and a selection of structural geological features (particularly faults and fractures) which have cut though the strata. The site additionally displays classic examples of landforms typically found along rocky coastlines, some of which have been nationally recognised. It is an attractive coastal site with easy access and has numerous links to the built heritage and social/economic history of the local area, with ample opportunity to enhance existing visitor information with some geology.

Site Photos

Photo ELC_4 P1: Ripples formed on the upper surface of a red sandstone bed within the Devonian sequence, visible on the intertidal shore platform east of Dunbar. The ripples appear asymmetrical, suggesting they were formed within a uni-directional flow, such as a river. Preservation of the ripples gives us an indication of the flow direction at the time of deposition, in this example, the ripples suggest a flow towards the south. Photo looking west. © BGS, NERC.

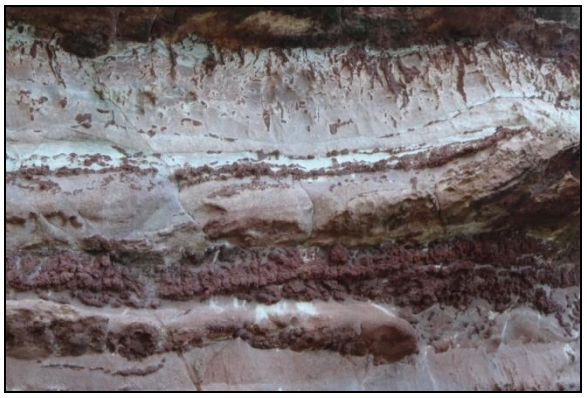


Photo ELC_4 P2: Excellent examples of palaeosols (fossilised soils) within the Kinnesswood Formation are revealed in an easily accessible cliff section above high water mark and immediately off the coastal path north of Dunbar. Red-brown 'roots' can be seen penetrating down through white sandstones from a sharp horizon. This horizon likely indicates a break in the deposition of sediments, long enough for plants to colonise and soils to start forming. The dark red horizon beneath the palaeosol may represent an iron-pan and indicate the level of the water table within the sediments at the time of formation. Photo looking south. Scale: image displays approx 1.5m of the sedimentary sequence. © BGS, NERC.

Photo ELC_4 P3: View looking east across the bay north of Winterfield Golf Course, displaying gently dipping strata belonging to the Ballagan Formation of early Carboniferous age. The sequence is made up of interbedded mudstones and cementstones, dissected by numerous faults and igneous intrusions (vents and dykes). © BGS, NERC.

Photo ELC_4 P5: Symmetrical ripples with rounded crests, preserved on the top surface of a bed within the Ballagan Formation. This type of ripple is indicative of a bi-directional flow, possibly shallow marine environment. Note also the finer cross-cutting trace fossils on top of the ripples, these are markings/impressions left by organisms travelling across or through the substrate. © BGS, NERC.

Photo ELC_4 P6: Quartz-dolerite dyke (dark coloured) intruding the paler sedimentary sequence of the Ballagan Formation. Note the sharp, sub-vertical margin between the two rock units, intrusions will often exploit natural weaknesses in the rock and may intrude along the plane of an existing fault or fracture. There is also evidence of a chilled margin being present, which would have formed as the hot magma cooled quickly against the cold rocks it intruded. Photo looking north. © BGS, NERC.

Photo ELC_4 P7: An excellent example of columnar jointing (similar to the spectacular Giant's Causeway in Ireland) is displayed in an outcrop of basalt at The Battery, Dunbar. Columnar jointing is a network of closely spaced joints/fractures in the rock, which formed as the hot basaltic magma cooled, contracted and fractured (typically into hexagonal columns) as it solidified. Although closed to the public at the time of visiting, the site is said to have extensive views of Dunbar, the Victoria and Cromwell harbours and have long range views to the Bass Rock and islands in the Firth of Forth. Photo looking north. © BGS, NERC.

Photo ELC_4 P8: Typical view of the red and brown bedded tuff and breccias, probably part of the volcanic cones associated with the Parade Vent, the largest of the early Carboniferous volcanic vents in the Dunbar area. The material has allowed the development of some superb rocky coastal landforms including an extensive shore platform which backed by high cliffs along which the coastal path meanders, allowing excellent views across to the cliff faces and down to the foreshore. Photo looking north-east. © BGS, NERC.

Photo ELC_4 P9: Close-up of lithified volcanic ash (tuff). Tuffs and breccia typically infill the numerous vents visible along the Dunbar coastline. This example is from within the Kirk Hill Vent and displays white feldspar crystals which have been incorporated into a fine-grained red-brown ash matrix. © BGS, NERC.

Photo ELC_4 P10: Small cliff section at the eastern side of Belhaven Bay, displaying raised beach deposits on top of reddened mudstones and cementstones of the Ballagan Formation. The beach deposits in the section are well-bedded and consist dominantly of shingle, sand and shells, and are representative of a time when sea level was higher than it is today. The contact between the two units can be described as an angular unconformity; 'angular' because the overlying sediments lie at a different angle to the strata below and 'unconformable' because the surface separating the two units represents a period of non-deposition or erosion. Photo looking north. © BGS, NERC.

Photo ELC_4 P11: A natural arch, located at the western end of Dunbar Castle, has formed in a promontory of rock jutting out from the coastline. Coastal erosion has selectively removed an area of softer/weaker rock to the extent that it has created a hole completely through it, leaving an 'arch' or 'bridge'. As erosion continues, the arch will enlarge and the roof eventually collapse and form a 'stack', examples of which (including the Dove Rock) can be seen further west along the coastline, along with other coastal erosion landforms such as caves and shore platforms. Note the old foundations of the castle still clinging to the cliff and one of the gun ports which helped defend the castle during its long and turbulent history. Photo looking north-west. © BGS, NERC.

Photo ELC_4 P12: Small-scale structural features can be studied within the Devonian strata east of Dunbar, above high water mark. The pale streaks running through the red sandstone highlight the presence of fractures/joints within the strata. As ground water migrated along the fractures and the adjoining strata it has caused reduction of some of the ferric oxide to ferrous oxide, which is slightly soluble. Leaching of the reduced iron has resulted in the red sandstone losing its colour. Such 'halos' form distinctive streaks in fractures cutting porous sandstones, the same effect is not seen in fractures cutting through mudstone due to their lack of available pore space. Photo looking south. © BGS, NERC.

Photo ELC_4 P13: View across the intertidal area east of Dunbar, the shore platform exposes many faults cutting through the Devonian sedimentary rocks. This example shows evidence of strike-slip movement. Within the fault plane the rocks tend to be ground up and broken, and so more easily eroded, leaving naturally formed linear gullies in the shore platform. Photo looking east. © BGS, NERC.

ELC_5: North Berwick Shore

Site Information

Location and Summary Description:

The site spans a 2 km section of coastline at North Berwick, extending from Partan Craig in the east, to the North Berwick Bay west. Cliff and coastal platform sections along the coast at the site expose dominantly volcanic and some sedimentary strata of Lower Carboniferous age.

National Grid Reference: Mid-point: 356026, 685471 West-end: 355204, 68549 East-end:356860, 685547	**Site type**: • Natural section/exposure • Natural landform • Natural view
Site ownership: Crown	Current use: Open Country
Field surveyors: Rachael Ellen and Eileen Callaghan	Current geological designations: North Berwick Coast (GCR ID: 1375); Part of Firth of Forth SSSI
Date visited: 27th August, 2014	Other designations: Firth of Forth SPA and Ramsar, North Berwick Conservation area.

Site Map

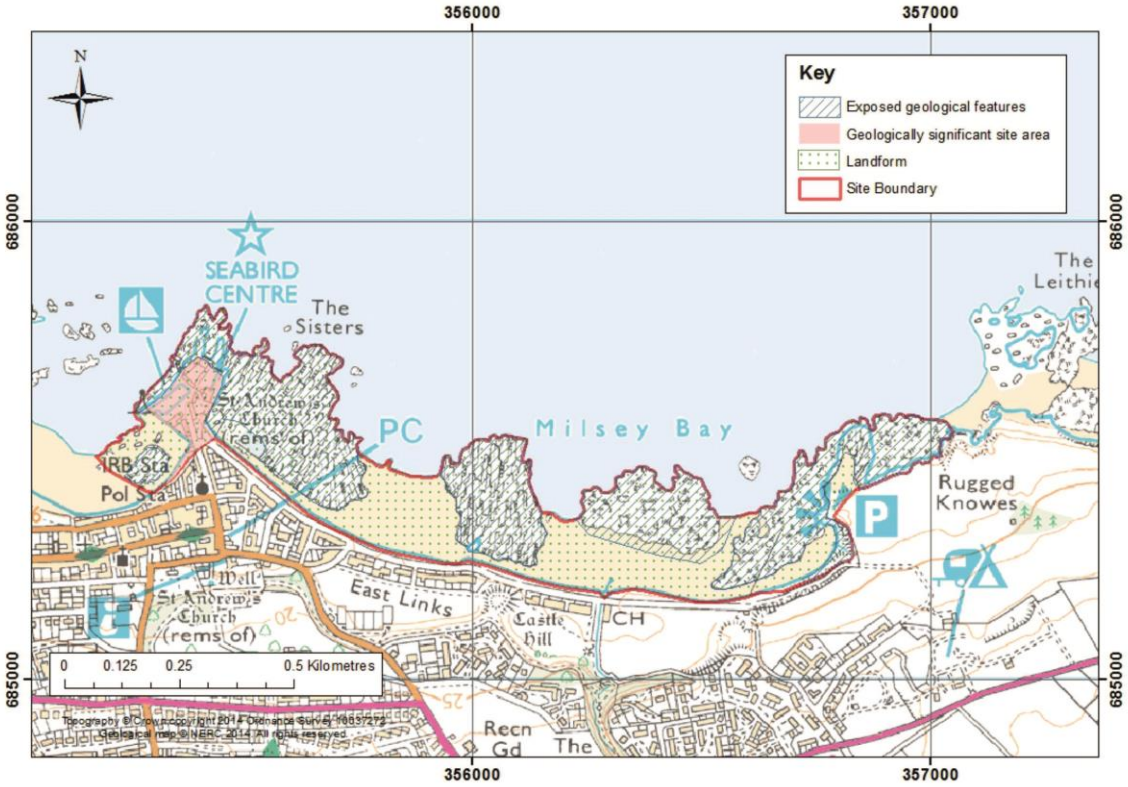


Figure 10: North Berwick Shore Location Map. The site comprises rocks exposed in shore platforms with intervening areas of beach. The exact area of bedrock exposure (blue hatched areas) is likely to vary in time due to changes in the beach morphology. Areas of geological significance include a viewpoint at the east edge of the site which overlooks the historic harbour of North Berwick to the west.

Site Description

Background

The site is located along the shore to the north of the popular seaside town of North Berwick. Historically, North Berwick was a fishing port, and its harbour was built around 1170. Red tuffs from Milsey Bay were quarried for building and oven lining in the late Middle Ages, and volcanic rocks (phonolite) from nearby North Berwick Law were quarried for building stones used in some of the buildings in the town.

Volcanic Rocks

The majority of the rocks exposed along the North Berwick shore are volcanic rocks belonging to the Garleton Hills Volcanic Formation (forming the lowermost unit of the Strathclyde Group). The Garleton Hills Volcanic Formation at this site comprise a sequence of plagioclase-macrophyric basalt, mugearite, plagioclase-olivine-clinopyroxene-macrophyric basalt, trachybasalt, basaltic tuff, volcanic breccia and olivine basalt.

Four basalt lava flows of slightly differing composition and mineralogy (resulting from evolution of chemical composition, in particular Si, Na and K, within the source magma chamber over time) are well exposed in the vicinity of North Berwick harbour and the Scottish Seabird Centre. A prominent ridge of massive grey-red basalt (formerly termed 'Markle Basalt'), some 17 m thick, contains abundant phenocrysts of feldspar, with rare pyroxene phenocrysts and pseudomorphs after olivine (ELC_5 P4). Toward Plattcock End, the top of the lava flow is more porous (due to brecciation of the lava surface during cooling), and containing many calcite filled vugs and amygdales (ELC_5 P5). Underlying the basalt is a fissile, dark grey-purple, fine-grained mugearite lava flow (ELC_5 P6) riddled with fractures, some of which are locally iron stained. Stratigraphically below the mugearite lava flow lies a lava flow of 'Dunsapie' type basalt, containing phenocrysts of feldspar and pyroxene (ELC_5 P7). This basalt is fairly massive in nature at its contact with the Scottish Seabird Centre (in the middle of the flow), whereas towards its base on the shore, is highly vesicular – a feature typical of the base of a lava flow due to a higher content of gas in the original molten flow. A 4 m thick trachybasalt lies below the 'Dunsapie' basalt. The trachybasalt has a reddened top with abundant calcite amygdales, with a grey-purple flow interior. The base of the trachybasalt is irregular where it overlies bedded tuff units to the east (ELC_5 P8).

The basaltic tuffs which dominate most of the remaining geology along the bay from the Scottish Seabird Centre to Partan Craig consist of red and green bedded tuffs, volcanic breccias and calcareous mudstone, dipping gently toward the northwest (ELC_5 P9). It is thought the calcareous mudstone beds formed in shallow lagoons during the early stages of volcanicity. The tuffs are composed of bedded fine-grained to coarse-grained, poorly-sorted, sub-angular fragments of calcareous mudstone and volcanic rocks, e.g. basalt and trachybasalt, derived from the explosive eruptions of volcanic vents.

The prominent Yellow Craig stack (so-called for the yellow lichen which grows on the rock) lies at the high water mark, composed of a dark grey, vesicular olivine-basalt with visible phenocrysts of feldspar and augite. Yellow Craig is a small oval plug of basalt which intruded into the basaltic tuffs. A well-developed chilled margin can be traced around the edge of Yellow Craig at low tide, marked by a pale, grey glassier basalt than the interior. Good contacts can be seen between the chilled margin and tuffs surrounding this intrusion (ELC_5 P10). Thin (<20 cm) dykes extend outward from Yellow Craig, intruding the basalt tuff sequences (ELC_5 P11).

At Partan Craig, a spectacular section is exposed in the cliffs to the east of Milsey Bay. The west-facing cliff is particularly striking, where a shallow synclinal structure can be seen (ELC_5 P12). The sequence in the cliffs starts with a striking red unit containing very large blocks (<2 m) of red tuffs and tuffaceous sandstones set in a matrix of tuff. The clasts are chaotic and rotated, and are thought to be the preserved remains of a debris flow at the edge of a vent (ELC_5 P13). Above this vent, volcanic breccias are found. The breccias and debris flow contain volcanic bombs, up to 1 m in size (ELC_5 P14). Some of the bombs are composed of basanite, containing crystals of nepheline (visible with a microscope), a mineral rarely found in Scottish rocks.

Sedimentary Rocks

Cementstones (ferroan dolomite) and calcareous mudstones are poorly exposed within the intertidal zone of Milsey Bay. These rocks form part of the Strathclyde Group, and crop out with a characteristic orthogonal fracture pattern (ELC_5 P1). They form as subordinate beds interbedded with the basaltic tuff, and stand a little prouder of the surface than the tuffs. Milsey Rocks were

submerged during the visit, but the Lothian Geology Excursion Guide describes outliers of massive pale sandstone interbedded with tuffs there. Red and green bedded calcareous mudstones (beds ~5 cm thick) interbedded with tuffaceous calcareous mudstones are exposed along the shoreline, with particularly good exposures found in North Berwick Bay, immediately south of North Berwick Harbour. Some of these rocks preserve discrete rippled surfaces. The brick red calcareous mudstones contain excellent examples of green reduction spots (ELC_5 P2), and rare fragments of crinoids and shells. The tuffaceous calcareous mudstones are coarse-grained, clast-supported, poorly-sorted with sub-angular clasts of creamy, altered feldspar crystals, along with volcanic and calcareous mudstone clasts (ELC_5 P3).

Structural Geology

Multiple faults bisect the strata at the site. The preferential erosion of softer fault rocks gives rise to conspicuous linear absences of rock in the foreshore. However, fault-related features are preserved in some rock platform areas and carbonate veins, slickensided surfaces and fractured deformation zones can be seen (ELC_5 P15).

An example of a syncline formed by shallow collapse of a vent is well exposed within the west-facing cliff of Partan Craig (ELC_5 P12). Small extensional, domino-block style faulting has developed within this collapse syncline (ELC_5 P16). There are excellent local deformation structures within the tuffs, presumably related to localised cryptovents – spectacular reverse faults in tuff sequences can also be identified within the wave cut platform in Milsey Bay.

Access and Additional Information

Access to the coastline is tide dependant, as most of the rocks are covered at high tide. The John Muir Way passes through the town of North Berwick, linking North Berwick Law, North Berwick and Yellow Craig plantation. Access to the coast at North Berwick is achieved by either parking at any of the numerous car parks within the town, or by taking a bus or train into the centre. A road can be followed most of the way along the shore at high tide. At the Scottish Seabird Centre there are interpretation boards describing the history of North Berwick Harbour and information about the surrounding islands. There is also an information board available overlooking the (now filled in) old harbour swimming pool, which gives a very brief geological account of North Berwick Law, and information about the town.

Stratigraphy and Rock Types	
Age: Lower Carboniferous	Formation: Aberlady Formation
Rock type: Sandstone, siltstones, calcareous mudstones, limestones, ferroan dolomite	
Age: Lower Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Basaltic tuff, trachybasalt, plagioclase-olivine-clinopyroxene-macrophyric basalt, mugearite, plagioclase-macrophyric basalt.	
Age: Carboniferous	Formation: Southern Scotland Dinantian Plugs and Vents Suite
Rock type: Tuff and breccia	
Age: Carboniferous	Formation: Midland Valley Carboniferous to Early Permian Alkaline Basic Dyke Suite
Rock type: Olivine-basalt	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Good access from various car parks/on-street parking within North Berwick. There are multiple public transport options to get to North Berwick, including by train.
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.
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.

	Some of the exposures are found below cliffs where potentially loose material may fall, therefore care should be exercised. Exposure near the harbour is restricted by a footpath and metal barrier – caution should be exercised if visiting outcrops beyond the barrier due to steep drops.
Access	Access along the foreshore/beach.
Current condition	The rocks can be covered in barnacles and seaweed. Rocks exposed at the high water mark are mostly free of vegetation, but contain patches of lichen which cover discrete features.
Current conflicting activities	Part of the section of walkway around the harbour was closed during the visit due to construction of a new pier.
Restricting conditions	Tide: many of the geological exposures are located in the intertidal range and are therefore covered at high tide.
Nature of exposure	Intertidal and beach exposures, low cliff exposures.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	North Berwick harbour dates back to at least 1177, used as a fishing port and ferry port for pilgrims headed to Fife. Historically there was a large open-air swimming pool at the north of the harbour, which closed in 1995.
Aesthetic landscape	Coastal landforms and historic town
History of Earth Sciences	The John Muir Way passes through North Berwick
Economic geology	Red tuffs in Milsey Bay were quarried for building and oven lining in the Middle Ages.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary Interest
Litho Stratigraphy	Regional	Good		
Sedimentology	Local	Poor		
Igneous/Mineral/ Metamorphic Geology	Regional	Excellent		X
Structural Geology	Local	Moderately good		
Palaeontology				
Geomorphology				

Site Geoscientific Value

The site comprises a sequence of extrusive lavas and volcanic tuffs, allowing interpretation of the volcanic environment during the Carboniferous. The interbeds of calcareous mudstones in the basalt tuffs provide additional environmental indicators during the Carboniferous in Scotland, representing shallow lagoons which formed during early onset of volcanism.

North Berwick Shore provides an excellent example of a Carboniferous volcanic sequence and related vents, and has regional 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 Yellow North Berwick which attracts visitors from further afield. The Scottish Seabird Centre and ease of access to Bass Rock is a significant tourist attraction
Education	The site displays a variety of features suitable for amateur geologists to study a sequence of igneous rocks representative of a series of volcanic eruptions. This site is an excellent locality for educational fieldwork. The geodiversity of this site could be further promoted by a series of **on-site** interpretation boards, geo-trail and distribution of geological leaflets.

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering/erosion; development of coastal defences may affect the geodiversity.
Potential use	On site interpretation, on site geo-trail, school and higher education, research

Geodiversity Summary

This site contains a good variety of geological features especially associated with volcanic strata. It exposes a sequence of the Lower Carboniferous Garleton Hills Volcanic Formation, along with a small section of the sedimentary Aberlady Formation within the sequence. The volcanic rocks seen allow interpretation of the emplacement of each formation, how they differ from each other and how different phases of volcanism and therefore eruption types represent the type of rock deposited. The coastline is attractive and has easy access. There are possibilities for adding geological interpretation to this site, potentially adjacent to an interpretation board already in place on Castle Hill.

Site Photos

Photo ELC_5 P1: Cementstones (ferroan dolomite) and calcareous mudstones interbedded with basaltic tuff in Milsey Bay. These interbedded sedimentary rocks are little more than 10 cm thick, and are recognizable in the field by their characteristic orthogonal fracture pattern. The deposition of these sediments during the Carboniferous would have occurred between volcanic eruptions (mostly ash fall), in shallow tropical lagoons. In the photo the town of North Berwick is visible on the skyline. Photo looking west. © BGS, NERC.

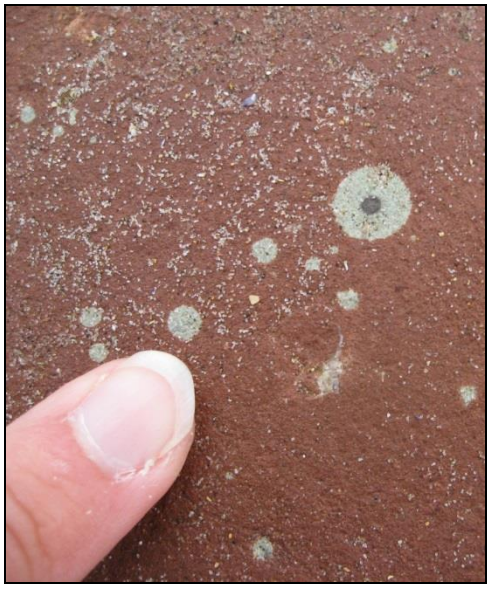


Photo ELC_5 P2: Perfectly circular pale-green reduction spots within red calcareous mudstones. Reduction spots are thought to form due to the reduction of Fe3+ to Fe2+, caused by the presence of organic particles in the original geological deposit. The dark centre of the larger reduction spot in this photo is likely to be the remains of an organic particle around which reduction occurred. © BGS, NERC.

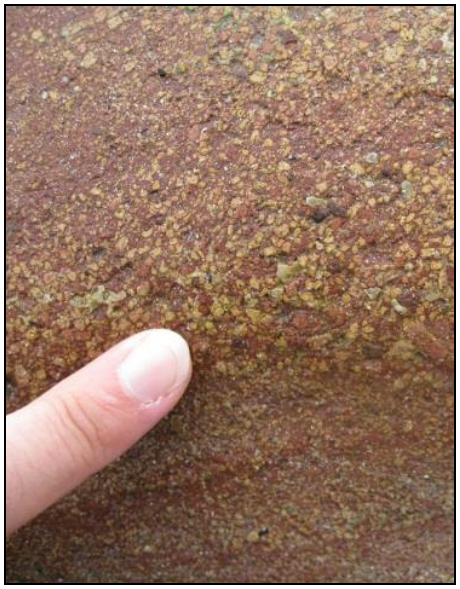


Photo ELC_5 P3: The calcareous mudstones contain tuffaceous layers, representative of ash-rich volcanic eruptions over the shallow lagoonal environments forming the calcareous mudstones. These tuffaceous layers are clast –supported, and composed of sub-angular clasts of creamy, altered feldspar crystals, along with volcanic and calcareous mudstone clasts. © BGS, NERC.

Photo ELC_5 P4: The grey-red basalt protecting the north-west wall of North Berwick harbour contains abundant mineral crystals, namely plagioclase feldspar phenocrysts (<5 mm in size) with occasional 1 cm euhedral labradorite feldspar phenocrysts set in a fine grained groundmass. Occasional <1 mm sized phenocrysts of pyroxene and olivine pseudomorphs can be identified within the face, such as the large crystal being pointed to in the photo. The presence of large crystals set in a fine grained groundmass are indicative of two phases of cooling in this lava flow – a slow, initial cooling forming larger crystals (probably within the magma chamber) and a fast, rapid cooling during eruption which formed the fine grained groundmass. © BGS, NERC.

Photo ELC_5 P5: The image shows a particularly fine example of calcite infilling a large vesicle in basalt, where all three of the calcite crystals natural cleavage planes can be seen The relatively porous top of the grey-red basalt forming the north-west wall of North Berwick harbour represents the flow top of an ancient lava flow. The tops of lava flows are typically very vesicular and gas bubble rich due to gas release from the bulk of the flow below, and its interaction with the open air during eruption. This increase in porosity allows groundwater in more easily in this part of the lava flow, allowing in some cases the deposition of Ca-bearing fluids and precipitation of calcite in these 'vugs'. © BGS, NERC.

Photo ELC_5 P6: View to the north looking out across the basalt lava flows to the north of North Berwick harbour. The high standing cliff to the left of the photo with large 'holes' is the porous flow top to the plagioclase-macrophyric basalt, whereas the beneath it (at the same level as the grey pipe), the slightly reddened mugearite lava flow is exposed. The basalts here dip toward the west. The island of Craigleith is visible in the background. © BGS, NERC.

Photo ELC_5 P7: Macroscopic detail of the 'Dunsapie Basalt', which lies stratigraphically below the mugearite lava flow at the north end of North Berwick harbour. The photo shows a large, <1 cm black phenocryst of pyroxene set in a fine-grained red-brown ground mass. © BGS, NERC.

Photo ELC_5 P8: View toward the Sea Bird Centre, to the west. The photo shows the 'Dunsapie' basalt cliff below the Sea Bird Centre, which is underlain by a reddened tuff unit (between the base of the cliff and seaweed covered rock platform). The wave cut platform is composed of trachybasalt, which forms an irregular base overlying tuffs (the reddened unit between the boulder foreground and small cliff). © BGS, NERC.

Photo ELC_5 P9: View toward the east along Milsey Bay, with bedded grey-green tuffs in the foreground. The coarser grained beds are volcanic breccia, and the finer grained beds tuff, representative of ash fall deposits during the Carboniferous. The bedding represents pulsatory jetting of material and showers of ash from a volcanic eruption.The volcanoes from which these were emplaced are preserved as vents situated along the coast, such as that of Parten Craig. The Parten Craig vent lies in the background of the photo. © BGS, NERC.

Photo ELC_5 P10: The westward margin of the Yellow Craig basalt plug displays a well-developed chilled margin at its contact with the bedded basaltic tuff sequence. The fresh dark gray-black basalt can be seen in the centre of the image, becoming increasingly paler as it approaches the reddened bedded tuffs (to the left of the hand lens). The chilled margin formed when the hot intruding basalt plug cooled rapidly against the cold tuffs, restricting crystal growth and resulting in very fine grain sizes. Photo looking north. © BGS, NERC.

Photo ELC_5 P11: Minor dykes radiate out from the Yellow Craig plug, composed of the same basaltic material as the plug. Here they can be seen intruding the bedded tuff units. The phonolite plug of Bass Rock is visible in the background. Photo looking toward the north-east. © BGS, NERC.

Photo ELC_5 P12: View toward the Partan Craig cliff, where a synclinal structure, formed by shallow collapse of a volcanic vent, is clearly visible. The layers of the syncline are composed of tuff, volcanic breccia, and debris flow deposits. Photo looking east. © BGS, NERC.

Photo ELC_5 P13: The red-grey strata above the geologist in the image is composed of chaotically orientated blocks <2 m in size, floating in a matrix of tuff. It is thought this 3 m thick unit represents the preserved remains of a debris flow at the side of a volcanic vent. The debris flow is overlain by grey beds composed of tuffs and volcanic breccias. Photo looking east. © BGS, NERC.

Photo ELC_5 P14: The volcanic breccias and debris flows of Partan Craig contain volcanic bombs, up to 1 m in size. The bomb photographed here is composed of nepheline-basanite, a light grey and friable volcanic rock. Sagging of the beds can be seen beneath the bomb where it would have plummeted on the then unconsolidated slopes of the volcano. © BGS, NERC.

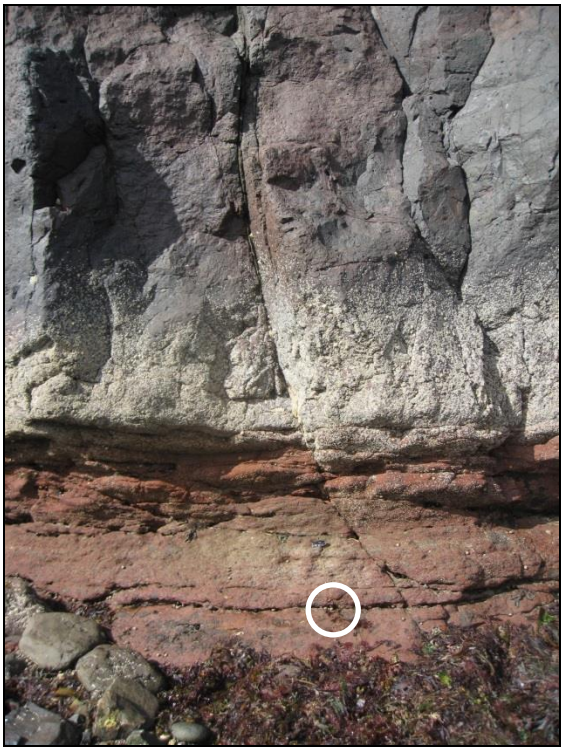


Photo ELC_5 P15: A 10 cm displacement normal fault cutting the 'Dunsapie' basalt and red tuff layer is exposed in the intertidal zone below the Sea Bird Centre. The plane of the fault is near vertical in the overlying basalt, and as it dissects the tuff becomes more inclined. This 'refraction' of the fault plane results from the differing strengths of the rock it is cutting – the basalt is strong and tends to fault with a vertical orientation, whereas the underlying tuff is weaker and shears more easily into an inclined orientation. Hand lens for scale (circled). © BGS, NERC.

Photo ELC_5 P16: Small extensional, domino-block style faulting has developed, accommodating movement within the Partan Craig vent as it was collapsing into its present day shallow syncline form. Photo looking to the north west. © BGS, NERC.

ELC_6: Yellow Craig Shore, North Berwick

Site Information

Location and Summary Description:

The site comprises a 3km section of coastline to the west of North Berwick, extending from the Yellow Craig Plantation up to Longskelly Point in the east, to the beach south of Eyebroughy in the west. The site displays strata of the Strathclyde Group, of Lower Carboniferous age. Younger strata of the Gullane Formation are exposed in the west and are underlain by older volcanic rocks of the Garleton Hills Volcanic Formation.

National Grid Reference: Mid-point: 350749, 686061 West-end: 349494, 685926 East-end: 352149, 686248	**Site type**: • Natural section/exposure • Natural landform • Natural view
Site ownership: Crown Estates	Current use: Open country
Field surveyors: Rachael Ellen, Sarah Arkley and Eileen Callaghan	Current geological designations: North Berwick Coast (GCR ID: 1375); part of Firth of Forth SSSI
Date visited: 25th April and 20th August, 2014	Other designations: Firth of Forth SPA and Ramsar, Listed wildlife site (Archerfield), Longniddrie – Berwick AGLV

Site Map

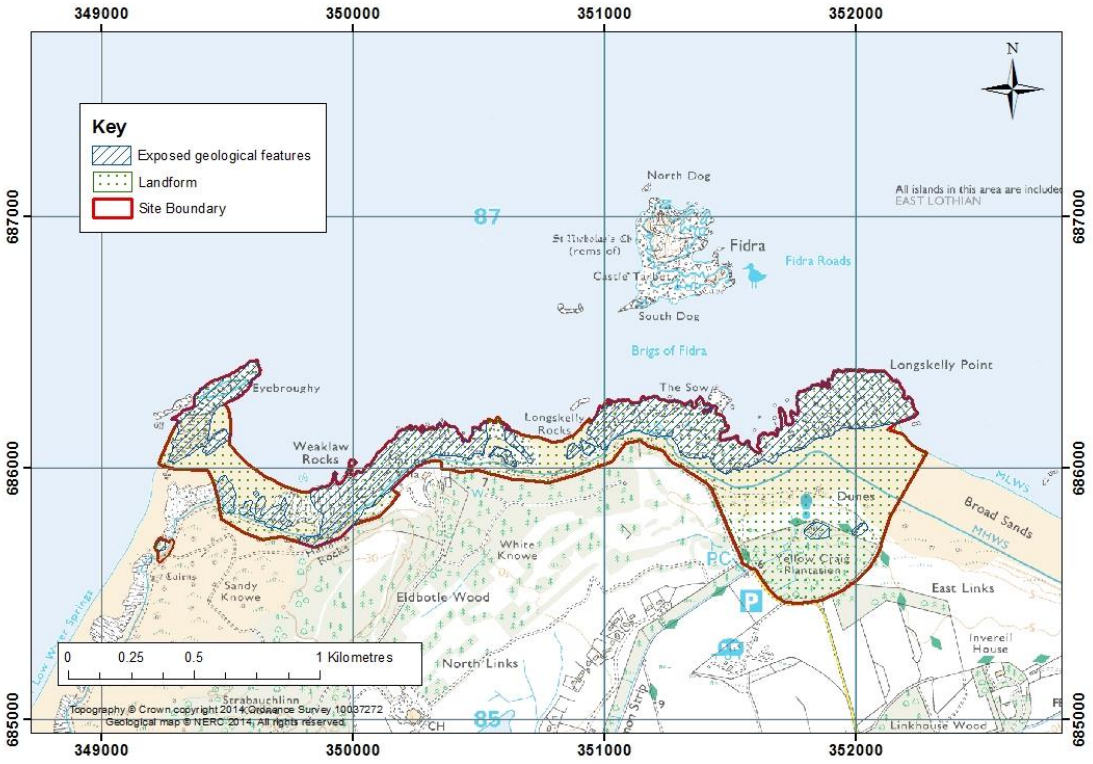


Figure 11: Yellow Craig Shore Location Map. Bedrock exposure (blue hatched areas) is likely to vary over time due to changes in beach morphology. Coastal landforms, including wave-cut platforms, dunes and areas of beach in the immediate vicinity of the main rock outcrops are included within the site boundary.

Site Description

Background and site area

The stretch of coastline between Yellow Craig to the east and Eyebroughy to the west is located to the west of North Berwick. The Broad Sands beach to the north of Yellow Craig is a popular place for walkers and tourists, and there are a number of walking trails and golf courses along the coast to the west.

Sedimentary Rocks

Sedimentary rocks of the Gullane Formation are exposed in the western part of the site. These rocks comprise a sequence of reddened cementstones, siltstones and mudstones, with sparse dolomitic and tuff beds. The siltstones and mudstones are finely bedded, and the cementstones display a characteristic orthogonal fracture pattern (Photo ELC_6 P1).

Volcanic Rocks

The majority of the rocks exposed along the Yellow Craig shore are extrusive volcanic rocks of the Garleton Hills Volcanic Formation. The volcanic rocks at this site comprise, from oldest to youngest, sequences of basalt, mugearite, trachyte tuff and trachyte, and vents of tuff and breccia formed by the explosive extrusion of lavas of varying composition from volcanoes and volcanic vents.

Yellow Craig Hill, at the eastern edge of the site, is composed of an olivine-microporphyritic, fractured, black basalt which forms part of the Yellow Craig Plantation Plug. There are excellent views from the top of this small hill (a roche moutonnee) toward Fidra and the Broad Sands beach. To the north-east of Yellow Craig Hill are exposures of volcanic breccia (also part of the Yellow Craig Plantation Plug) composed of a brown-grey tuff containing rounded bombs and baked angular blocks (Photo ELC_6 P3).

The intertidal rocks of Longskelly Point are composed of an intrusive sheet of fine-grained olivine-basalt, partially vesiculated, with weak polygonal jointing (Photo ELC_6 P4). To the west, a plagioclase-macrophyric basalt (historically known as the Markle Basalt) flow is exposed along the coast. The basalt contains numerous large (<7mm) feldspar phenocrysts (Photo ELC_6 P5), and has a gnarled and knobbly appearance along the shore. It is also cut in multiple places by calcite veins, and autobrecciated in the upper part of the flow (Photo ELC_6 P6).

Overlying the plagioclase-macrophyric basalt is a fissile, dark grey-purple, fine-grained mugearite riddled with calcite veins and vugs. It contains occasional feldspar phenocrysts <4mm in size, and amygdales filled with calcite <2cm in diameter. There is localised iron staining along fractures within the mugearite, and excellent examples of concentric iron bands surrounding a core of bleached mugearite (Photo ELC_6 P7), likely representing the weathered top of a mugearite flow within the sequence. The mugearite contains in places rip up clasts of the underlying Markle basalt caught up as the lava flowed across the surface of the older flows.

The mugearite is stratigraphically overlain by a trachytic tuff, formed by the deposition of ash following an explosive volcanic eruption. The contact between this tuff and mugearite is clearly defined on the coast to the north of Marine Villa, and is traceable for approximately 150 m along the intertidal platform to the west. At the contact, the mugearite displays an irregular, slaggy amygdaloidal flow top (Photo ELC_6 P8) and is much reddened from its typical dark grey-purple, suggesting weathering of the lava top after emplacement. The overlying red - green trachytic tuff is bedded, with coarse agglomeratic beds and fine ash beds (Photo ELC_6 P9). The coarser volcanic breccia beds locally truncate finer grained (ashy) units, suggesting that mass flows were active during deposition of the tuff (Photo ELC_6 P10). Good exposures through the tuff sequence can be found in low cliffs at the high water mark near Marine Villa.

Bedded, yellow-brown tuffs and breccias containing dolomitic fragments form the Weaklaw Vent, exposed at the west of the site. Volcanic vents such as this are likely to have emplaced the locally surrounding lavas and tuffs.

Structural Geology

Minor folds are visible within the dolomite tuff and dolomitic units of the Gullane Formation (Photo ELC_6 P2), thought to be related to a nearby fault. There are multiple slickenlined planes visible within the trachytic tuff, particularly in the lower parts of the unit (Photo ELC_6 P12). These slickenlined planes are also thought to be related to the fault also responsible for folding of the Gullane Formation rocks. Abundant calcite veins cross cut the mugearite and markle basalts, filling in fractures which

probably formed soon after cooling of the basalt flows.

Quaternary Deposits and Landforms

Rock exposures along the coast comprise erosional cliffs and wave-cut platforms, interspersed with sandy beaches. Blown sand (dunes) form significant features across much of the site, particularly so at the west end of Broad Sand, and to the south of the bay between Weaklaw Rocks and Eyebroughy. A raised beach and glacially smoothed rock exposures are found to the north-east of Yellow Craig Hill.

Access and Additional Information

Access to the coastline is tide dependant, as most of the rocks are covered at high tide. The John Muir Way passes through the Yellow Craig Plantation. Access from the Yellow Craig Plantation car park is easy and the path can be followed to the beach, or to the top of Yellow Craig hill. There is a good network of paths surrounding the hill. The shoreline can be walked along either on the sandy beach, or if the tide is high, a rough track in the dunes adjacent to the shore. At the Yellow Craig Plantation car park there are interpretation boards describing the flora and fauna of Yellow Craig. The interpretation boards also describe the area's historical links with Robert Louis Stevenson who was inspired the small islands in the Firth of Forth visible from Yellow Craig (namely Fidra).

Stratigraphy and Rock Types	
Age: Lower Carboniferous	Formation: Gullane Formation
Rock type: Sandstone, siltstones, mudstones, occasional tuffs and dolomites	
Age: Lower Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Trachytic tuff, trachyte, mugearite, plagioclase-macrophyric basalt.	
Age: Carboniferous	Formation: Southern Scotland Dinantian Plugs and Vents Suite
Rock type: Tuff and breccia, olivine-macrophyric basalt	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	Good access from car park located at Yellow Craig Plantation. There are also public toilets available at the car park.
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.
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. Some of the exposures are found within low cliffs where potentially loose material may fall, therefore care should be exercised.
Access	Access along the foreshore/beach, there are numerous footpaths around the site from the car park.
Current condition	The rocks can be covered in barnacles and seaweed. Rocks exposed at the high water mark are mostly free of vegetation, but contain patches of lichen which cover discrete features.
Current conflicting activities	None
Restricting conditions	Tide: many of the geological exposures are located in the intertidal range and are 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	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'. Robert Louis Stevenson also used Marine Villa, a house on the coast in the centre of the site, as the location for his short novel 'The Pavilion on the Links'.
Aesthetic landscape	Coastal
History of Earth Sciences	John Muir Way passes through Yellow Craig Plantation
Economic geology	No known association

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary Interest
Litho Stratigraphy	Regional	Excellent		X
Sedimentology	Local	Poor		
Igneous/Mineral/ Metamorphic Geology	Regional	Excellent		X
Structural Geology	Local	Good		
Palaeontology				
Geomorphology	Local	Good		

Site Geoscientific Value

The site comprises a complete sequence of extrusive lavas, volcanic tuffs and volcanic vent material, allowing interpretation of the subaerial volcanic environment during the Carboniferous.

Yellowcraig Shore provides an excellent example of Carboniferous extrusive volcanic rocks with regional lithostratigraphical 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 Yellow Craig Plantation which attracts visitors from further afield.
Education	The site displays a variety of features suitable for amateur geologists to study a sequence of igneous rocks representative of a series of volcanic eruptions. This site is an excellent locality for educational fieldwork. The geodiversity of this site could be further promoted by a series of **on-site** interpretation boards, geo-trail and distribution of geological leaflets.

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion; development of coastal defences may affect the geodiversity
Potential use	On site interpretation, on site geo-trail, school and higher education, research

Geodiversity Summary

This site contains a good variety of geological features associated with volcanic strata. It exposes a sequence of the Lower Carboniferous Garleton Hills Volcanic Formation, along with a small section of the overlying sedimentary Gullane Formation. Features of the volcanic rocks seen indicate the emplacement mechanism and different phases of volcanism, allow interpretation of a sequence of eruption types. The coastline is attractive and has easy access. There are possibilities for adding geological interpretation to this site, especially at the car park of Yellow Craig Plantation, and on top of Yellow Craig Hill.

Site Photos

Photo ELC_6 P1: Intertidal exposure of reddened cementstones with a charactersitic orthogonal fracture network. Photo is looking to the north. © BGS, NERC.

Photo ELC_6 P2: Subtle folding is found within the dolomitic and tuffaceous layers of the Gullane Formation. It is thought the folding is related to a nearby fault. Seaweed and barnacles largely obscure the outcrop in the intertidal zone. Photo is looking toward the west. © BGS, NERC

Photo ELC_6 P3: The breccia of the Yellow Craig Vent is a brown-grey tuff, containing baked angular clasts of volcanic material, such as those pictured above. © BGS, NERC.

Photo ELC_6 P4: Polygonal fracturing within the basic intrusion of Longskelly Point. The basalt here displays well formed vesicles, relict gas bubbles which have been preserved after the basalt cooled deep underground. © BGS, NERC

Photo ELC_6 P5: Detail of feldspar phenocrysts within the plagioclase-macrophyric basalt. The plagioclase phenocrysts are set within a fine grained groundmass, suggesting before this lava was emplaced, it cooled in two phases – a rapid cooling (forming miniscule crystals in the groundmass), and a slower, prolonged cooling (forming plagioclase feldspars). © BGS, NERC.

Photo ELC_6 P6: Example of mineralised autobrecciation at the top of a lava flow of the plagioclase-macrophyric basalt. Autobrecciation occurs when a new lava flow rumbles over the top of a pre-existing one, picking up loose or unsolidified material and rolling it along beneath the new flow. This zone is also susceptible to mineralization, due to the large pore spaces left during such a process. © BGS, NERC

Photo ELC_6 P7: Concentric iron bands rim a bleached core of iron-depleted mugearite. Note the unaltered grey-purple mugearite outsite the iron concreations. The concentric iron-banding is produced by segregation of iron oxide. There are also zones of calcite mineralisation within the iron bands. © BGS, NERC

Photo ELC_6 P8: The top of the mugearite is excellently exposed, displaying the irregular, amygdaloidal slaggy top of the flow. Examples of these slaggy tops are seen today in volcanic areas such as Hawaii and Iceland. The top of a lava flow is susceptible to mineralization, due to increased pore space following gases escaping through the top after emplacement. At the locality, mineralisation of the vesicles is found (white specks in photo above). © BGS, NERC

Photo ELC_6 P9: Low cliffs expose excellent sections through the bedded trachyte tuff succession, such as the one pictured above. The unit coarsens upwards, and is composed of beds a few cm thick ranging from very fine material (ash) to coarse material (agglomeratic). © BGS, NERC

Photo ELC_6 P10: Agglomeratic units within the trachytic tuff truncate underlying ashy units, suggesting as the agglomeratic units were emplaced, it scoured out the pre-existing ash unit, formed from a previous eruption. © BGS, NERC.

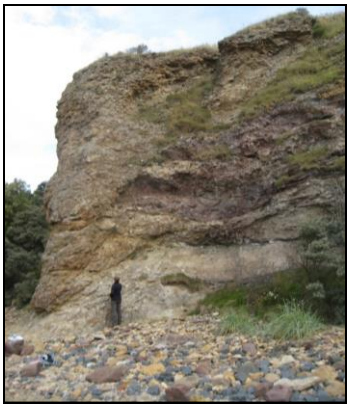


Photo ELC_6 P11: A cliff section at the Hanging Rocks forms the edge of the Weaklaw Vent, where the yellow-brown tuffs and breccias cross cut the reddish trachytic tuff sequence and overlying trachyte lava flow, which form the cliff in the right of the photo . Photo looking toward the east. © BGS, NERC

Photo ELC_6 P12: Example of a polished slickenlined plane within the trachytic tuff. Such slickenlined planes, in this cast mineralised by calcite, are numerous throughout the tuffs, thought to relate to a nearby larger fault. The slickenlines in the tuff indicate a normal sense of motion. © BGS, NERC

ELC_7: Old Markle Quarry, East Linton

Site Information

Location and Summary Description:
Disused basalt quarry, located ~0.5 km west of the village of East Linton. The site displays the type locality of the 'Markle Basalt Lava', which is of widespread occurrence in the lower Carboniferous lavas of the Midland Valley. The basalt forms part of the Garleton Hills Volcanic Formation, part of the Strathclyde Group of the lower Carboniferous. Historically, the quarry was worked at least until 1854, and closed sometime before 1895.

National Grid Reference: Mid-point: 358385,677010	**Site type**: • Artificial quarry works
Site ownership: Not known	**Current use**: Disused, agricultural land
Field surveyors: Sarah Arkley & Rachael Ellen	**Current geological designations**: None
Date visited: 16th April, 2014	**Other designations**: Markle Quarry Pond Local Biodiversity Site

Site Map

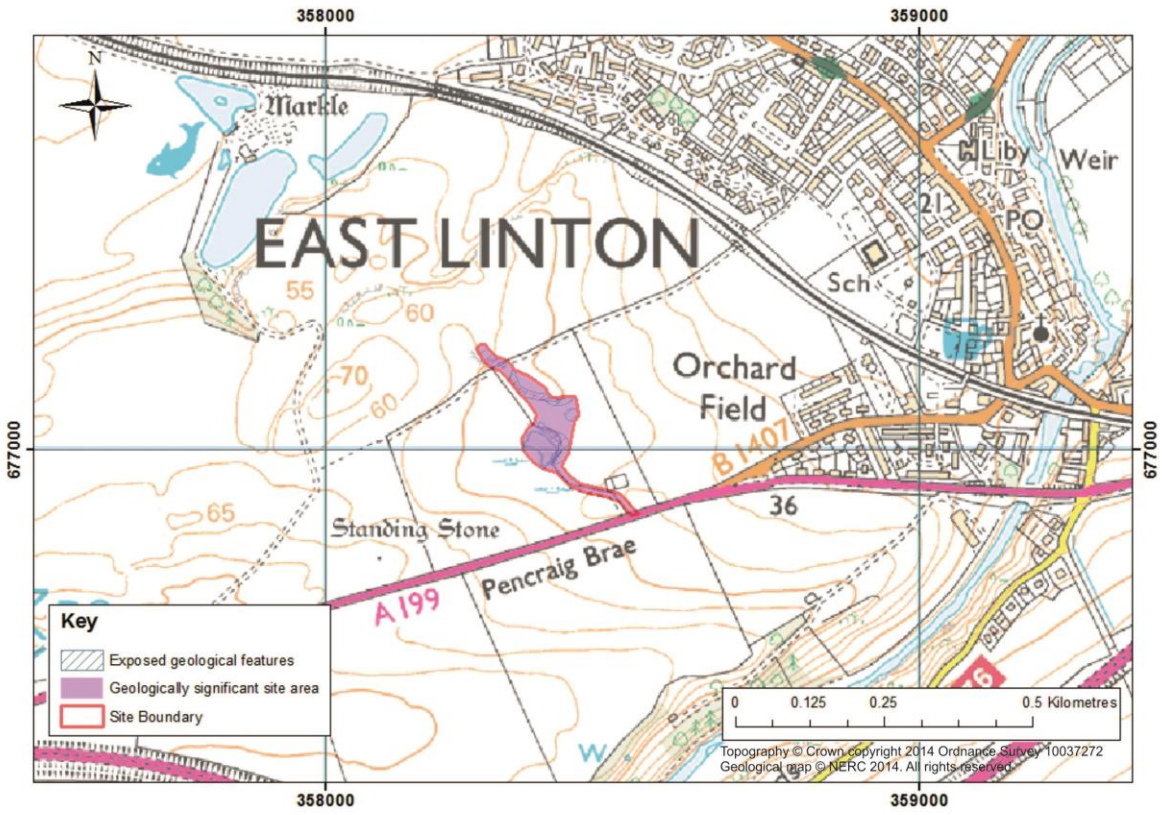


Figure 12: Old Markle Quarry Location Map. The site boundary has been drawn to include rock outcrops to the north of the quarry, as they are of the same rock type and will provide alternative exposures to examine should high water levels in the pond of the quarry restrict access. Access and general viewpoints are also included within the geologically significant site area.

Site Description

Background

The quarry was active in the early 1800s, for extraction of basalt presumably for aggregate. The plagioclase-macrophyric basalt flow exposed in the quarry is known traditionally as the 'Markle Basalt Lava' type, and is of widespread occurrence in the lower Carboniferous lavas of the Midland Valley. This quarry represents the type locality of the Markle Basalt type. The quarry floor is now flooded, but quarry faces remain accessible for examination (Photo ELC_7 P1). Should water levels rise and access be restricted, there are natural exposures to the north of the quarry which could be examined.

Volcanic Rocks

The quarry face displays a 7–8 m thick basalt lava, generally massive with sub-vertical joints, and weakly developed columnar jointing in unworked faces (Photo ELC_7 P2). The basalt flow is composed of abundant large (<1 cm) plagioclase feldspar phenocrysts and pseudomorphs after olivine phenocrysts (<0.3 cm), set in a fine grained grey-red groundmass ((Photo ELC_7 P3). The pseudomorphs after olivine contain hematite, chlorite and a small component of quartz (Smith, 1959).The basalt is reddened throughout the outcrop due to hematisation, with locally concentrated alteration surrounding fractures. The feldspar phenocrysts are tabular to blocky in nature, and white in colour with a visible cleavage plane. The olivine pseudomorphs are more lobate in nature than the feldspars. The basalt is non-vesicular at the base, becoming increasingly vesicular (exhibiting elongation in places, suggesting flow-aligned morphology – see Photo ELC_7 P4) and fissile toward the top 1 – 2 m of the outcrop, interpreted as the near surface facies of an 'aa' flow type (lava flow which cools as large blocks with a rough, jagged surface). Mineralised fracture planes occur along the sub-vertical joints, possibly calcite.

Structural Geology

There are abundant examples of slickenlined joints (evidence of rock on either side of the joint moving with respect to the other), with the slickenlines trending in an ENE-WSW orientation (Photo ELC_7 P5).

Access and Additional Information

Within the old quarry itself there is debris and boulders along with boggy ground, making an uneven walking surface. The quarry is also partially filled with water, but the quarry face is accessible in places. Broken loose boulders can be collected. Rock face seems fairly stable, although weathering and fracturing in places may potentially lead to rock fall, and therefore care should be taken whilst examining this outcrop. This quarry is featured as an excursion in the Lothian Geology Excursion Guide.

Stratigraphy and Rock Types

Age: Lower Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Basalt, plagioclase-macrophyric	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Good access from pavement along the A199, and parking by the roadside either along Haddington Road (B1407), or along the road in the Orchard Field housing estate. Enter through a farmer's gate from pavement to enter quarry site.
Safety of access	Pavement is adjacent to a busy and fast road, and is necessary for site access. The path to the quarry is along a rough track. Rough uneven ground on sides and floor of quarry, overgrown and boggy in places. Deep water in front of quarry walls should be avoided.
Safety of exposure	Care should be taken as in all quarries, and an assessment made of each face before approaching. The quarry faces are high, and potentially loose material may fall, therefore care should be exercised. There is loose material underfoot, overgrown by grass and weeds.

Access	Accessed via tracks in agricultural land
Current condition	The condition is good with rock faces generally well exposed, however moss and lichen cover the basalt in places on the quarry faces. A few trees and vegetation may obscure views in summer, and there are minor amounts of farmer debris, boulders, and wood in places.
Current conflicting activities	None
Restricting conditions	After heavy rainfall the water in front of the quarry face may rise so that access to the lower parts of the quarry faces is not achievable.
Nature of exposure	Vertical quarry faces

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	No known association
Aesthetic landscape	Old quarry on the edge of East Linton, revealing underlying geology
History of Earth Sciences	Type locality of Markle basalt
Economic geology	Quarried in 1800, activity ceased between 1854 and 1895. Use unknown, probably for road metal.

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology	Regional	Good	Smith, 1959	X
Structural Geology	Local	Poor		
Palaeontology				
Geomorphology				

Site Geoscientific Value

This site is the type section for ‘Markle Basalt’ (now a disused term for the plagioclase-macrophyric basalt exposures throughout the Midland Valley of Scotland), and is therefore the most important section through this part of the Carboniferous volcanic sequence in the region.

The Old Markle Quarry provides a good example of typical Carboniferous basalt lava flow, with regional significance.

Assessment of Site: Current site usage

Community	The quarry is on the outskirts of the town of East Linton, and rarely visited by the local community. It is likely to be frequented by the occasional geologist due to its significance as the type locality of Markle Basalt.
Education	The site is the type locality for the Markle Basalt lava, and is exposed particularly well, with plenty of fresh faces for examination of the large plagioclase phenocrysts. The quarry would act as an excellent reference point to those interested in igneous rocks of the lower Carboniferous of the Midland Valley of

	Scotland. **On-site interpretation boards** would be appropriate for this site.

Assessment of Site: Fragility and potential use of the site	
Fragility	Natural overgrowth, geohazard
Potential use	Research, Higher/Further Education, School Education, On-site interpretation

Geodiversity Summary

The main value of this site is its geological association of being a type locality for a regionally widespread and common rock type. It contains excellent exposures of the Markle Basalt, a basalt type common and widespread throughout the central belt of Scotland. The site exposes an excellent cross section through a basalt lava flow containing abundant feldspar phenocrysts, vesiculated flow tops and other features typical of a basalt lava flow (e.g. sub-vertical cooling joints).

Site Photos

Photo ELC_7 P1: Overview of Old Markle Quarry. The floor of the quarry is filled with water, and the edges of the pond are littered with old bits of wood, rock debris, and other loose material. The accessible rock face is shown in this photo. Photo looking south. © BGS, NERC.

Photo ELC_7 P2: Weakly developed columnar jointing within the plagioclase-macrophyric basalt. Columnar joints form when a basalt flow is cooling, with the cooling surface (e.g. ground or air) typically perpendicular to the orientation of the joints. In this case, the columnar joints are near vertical, suggesting the cooling surface was sub-horizontal (e.g. ground or air). Photo looking west. © BGS, NERC.

Photo ELC_7 P3: Detail of the plagioclase-macrophyric basalt at this locality. The groundmass is grey-red, with abundant phenocrysts of white, blocky to equant feldspar phenocrysts. The reddish crystals which are lighter than the ground mass are pseudomorphs after olivine. © BGS, NERC.

Photo ELC_7 P4: Detail of elongated vesicles (relict gas bubbles) within the basalt lava flow. The vesicles are elongated, suggesting they have been aligned during motion within the lava flow. This so called 'vesicle flow alignment' suggests a movement of the lava flow from left to right in this photo. © BGS, NERC.

Photo ELC_7 P5: Slickenlines on joint within basalt. Slickenlines are 'scrapes' left on joint surfaces when the rock on either side of the joint has moved against the other. The movement often polishes the joint surface, as is the case in a lot of the slickenlines surfaces at this locality.

ELC_8: Blaikie Heugh – Balfour Monument

Site Information

Location and Summary Description:

The Balfour Monument sited on the 15m high lava escarpment of Blaikie Heugh offers stunning views of Traprain Law, Berwick Law and the Garleton Hills (Photo ELC_8 P1). The site is approximately 2.5km north-east of the village of Garvald. The site displays the "Craiglockhart Basalt Lava" belonging to the Garleton Hills Volcanic Formation. To the east of this site, a smaller escarpment exposes a hornblende-bearing trachybasaltic lava flow.

National Grid Reference: Mid-point: 357631, 673049 West end: 357373, 672969 East end: 357895, 673165	**Site type**: • Natural section • Natural exposure • Natural view
Site ownership: Unknown	Current use: Agricultural Land
Field surveyors: Rachael Ellen and Eileen Callaghan	Current geological designations: None known
Date visited: 10th June 2014	Other designations: The Balfour Monument is listed

Site Map

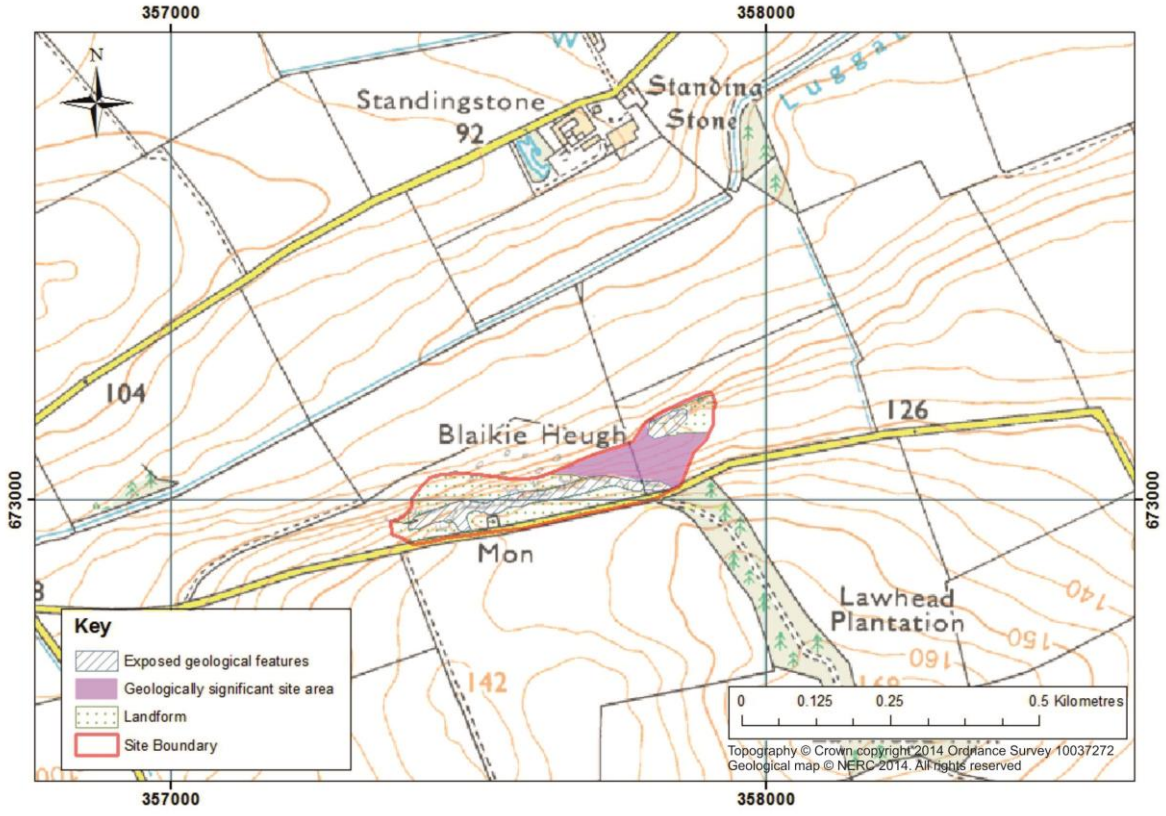


Figure 13: Blaikie Heugh Location Map. The site boundary includes rock and landforms including boulder fields lying at the base of the cliff, the cliff escarpment and streamlined bedrock. The area between the two rock exposures is classed as geologically significant for access between the sites and for an appreciative view point toward the cliffs.

Site Description

Background

The Balfour Monument is located by the roadside on an escarpment overlooking Traprain Law. The Monument is a red sandstone obelisk, dedicated to James Balfour (1820–56), a Major Commandant of the East Lothian Yeomanry Cavalry. The Blaikie Heugh escarpment is formed of an olivine-clinopyroxene-macrophyric basalt traditionally known as the 'Craiglockhart Basalt' type, which is of widespread occurrence in the lower Carboniferous lavas of the Midland Valley. A nearby escarpment to the east is also of geological interest, being composed of a hornblende-bearing trachybasalt.

Volcanic Rocks

The escarpment below the Balfour Monument (Photo ELC_8 P2) is composed of an olivine-clinopyroxene-macrophyric basalt, comprising abundant large (<1cm) augite pyroxene phenocrysts and brown-red pseudomorphs after olivine (<0.5 cm), set in a fine grained groundmass. The main outcrop is 15 metres in height with rough columnar jointing observed (Photo ELC_8 P3). The basalt has a dark grey groundmass with phenocrysts of augite and pseudomorphs after olivine. The augite phenocrysts (Photo ELC_8 P4) are black with an equant crystal shape, and have visible cleavage planes. The olivine pseudomorphs (Photo ELC_8 P5) have been replaced by a reddish-brown clay, and are equant-lobate in crystal shape. Fine, mm scale 'ribs' cross cut the olivine pseudomorphs, possibly a relict feature of the original olivine's crystal fractures. Large boulders of the basalt can be examined in the boulder-field lying at the base of the cliff.

The minor escarpment just to the east of the Balfour Monument (moulded and streamlined by glacial erosion) is composed of a westward dipping hornblende-bearing trachybasaltic flow (an alacime-bearing hornblende-phyric trachybasalt), which stratigraphically underlies the olivine-clinopyroxene macrophyric basaltic lava found at Blaikie Heugh. The minor escarpment is approximately 3 metres in height (Photo ELC_8 P6). The trachybasalt is massive and well-jointed, with the rock itself much decomposed and reddened. Mineralised veins and pseudomorphed (oxidised) hornblende phenocrysts (Photo ELC_8 P7) are vaguely visible within the rock.

The volcanic rocks described above form part of the Garleton Hills Volcanic Formation, part of the Strathclyde Group of the lower Carboniferous.

Access and Additional Information

Access to the site is at the Balfour Monument off a minor road [357549 672961]. There is parking in a lay by at the monument. The monument is on an artificially made platform with a drop of approximately 1.5 m to the field. The escarpment drops steeply from the raised area and it is best to access the base of the escarpment by either heading east or west. The best and easiest accessible outcrop is approximately 250 metres east of the monument near the boundary fence. The main escarpment can be accessed by descending the slope and traversing the field. The smaller escarpment approximately 370 metres north-east of the monument can only be accessed by climbing over a fence.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Olivine-clinopyroxene-macrophyric basalt (Craiglockhart Basalt)	
Age: Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Trachybasalt	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Parking in the lay by at the Balfour Monument.
Safety of access	Care has to be taken as the monument is at the top of the escarpment looking down onto the fields. The ground is steep and traversing the field either east or west gives access to the base of the escarpment. There is

	also a boulder field at the foot of the escarpment, and loose rock is covered by grass. The minor escarpment to the north-east is accessed through fenced pastures.
Safety of exposure	Care should be taken and an assessment made of the escarpment face before approaching as loose material may fall.
Access	Access via agricultural land.
Current condition	Lichen covers the basalt but generally well exposed.
Current conflicting activities	None
Restricting conditions	Livestock in fields.
Nature of exposure	Escarpment

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	Balfour Monument erected in 1858 in memory of James Maitland Balfour of Whittinghame, father of Prime Minister Arthur James Balfour.
Aesthetic landscape	Panoramic views from the monument of the Pentland Hills, Edinburgh, Fife, and in East Lothian, the Garleton Hills, Berwick Law, Traprain Law and the Bass Rock.
History of Earth Sciences	No known association
Economic geology	No known association

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary Interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology	Regional/ National	Moderately good		X
Structural Geology				
Palaeontology				
Geomorphology				

Site Geoscientific Value

The site comprises exposures of two different kinds of basalt, relevant to the interpretation of the volcanic environment during the Carboniferous. There are few examples of hornblende-bearing trachybasalts across East Lothian, whereas the 'Craiglockhart' basalt is found across the Midland Valley of Scotland.

Blaikie Heugh provides a moderately good example of Carboniferous basalt lava flows, with national to regional significance.

Assessment of Site: Current site usage

Community	The Balfour Monument at the site is of historical interest, and is likely to attract some visitors. The views from the monument are also impressive.

Education	The site presents moderately good exposures of 'Craiglockhart' type basalt and hornblende-bearing trachybasalt, and affords excellent views across much of East Lothian. This site may be a good locality for educational fieldwork relating to the volcanic environment of the Carboniferous in Scotland, and on-site interpretation board explaining the geology of the view from the monument may also be appropriate.

Assessment of Site: Fragility and potential use of the site	
Fragility	Natural overgrowth and erosion and weathering of feature.
Potential use	Higher/further education, school education, on-site interpretation

Geodiversity Summary

Blaikie Heugh contains natural exposures of two types of basalt lava flows belonging to the Garleton Hills Volcanic Formation: anolivine-clinopyroxene-macrophyric basalt traditionally known as the 'Craiglockhart Basalt' type, and a hornblende-bearing trachybasalt. Both of these lava types are not well distributed throughout East Lothian, and this site represents an opportunity to study both of the lava types at the same time. A trachybasalt is also exposed at North Berwick Shore, but exposure is limited in the intertidal zone. The site also affords historical links (Balfour Monuments) and panoramic views across East Lothian.

Site Photos

Photo ELC_8 P1: View of Traprain Law and Berwick Law from Balfour Monument, looking north-east. © BGS, NERC.

Photo ELC_8 P2: View of Blaikie Heugh escarpment and monument, looking west. The rocks forming the escarpment are of 'Craiglockhart' basalt, an olivine-clinopyroxene-macrophyric basalt. © BGS, NERC.

Photo ELC_8 P3: Faint columnar jointing seen in olivine-clinopyroxene-macrophyric basalt, exposed in the escarpment of Blaikie Heugh. Photo looking south-east © BGS, NERC.

Photo ELC_8 P4: Detail of an augite (type of pyroxene) phenocryst within the olivine-clinopyroxene-macrophyric basalt, exposed in the Blaikie Heugh escarpment. Finger (resting on white lichen) is pointing toward a black, equant augite phenocryst. © BGS, NERC.

Photo ELC_8 P5: Detail of a pseudomorph after olivine within the olivine-clinopyroxene-macrophyric basalt, exposed in the Blaikie Heugh escarpment. Finger (resting on white lichen) is pointing toward a red-brown pseudomorphs after olivine. Fine mm-scale ribs, cutting across the pseudomorph from left to right, may represent relict crystal fractures of the original olivine. © BGS, NERC.

Photo ELC_8 P6: Minor escarpment to the east of Blaikie Heugh escarpment, displaying a massive, well-jointed trachybasalt flow. Photo looking east. © BGS, NERC.

Photo ELC_8 P7: Detailed view of the trachybasalt flow. The rock is stained red, due to oxidisation of (pseudomorphed) hornblende phenocrysts. © BGS, NERC.

ELC_9: Kippielaw Scarp

Site Information

Location and Summary Description:

Kippielaw Scarp is situated 1.5 km south-west of the village of East Linton and approximately 800 metres to the north of Traprain Law. The outcrop at Kippielaw Farm is a basaltic lava flow of "Dunsapie" type basalt as described by MacGregor (1928). The Dunsapie basalt type is a macroporphyritic basalt composed of plagioclase, olivine and clinopyroxene phenocrysts, and forms part of the Garleton Hills Volcanic Formation.

National Grid Reference: Mid-point: 358373, 675519	**Site type**: • Natural section • Natural exposure • Artificial quarry works
Site ownership: Traprain Farm	Current use: Agricultural land
Field surveyors: Rachael Ellen and Eileen Callaghan	Current geological designations: none
Date visited: 10th June 2014	Other designations: Traprain Grasslands Local Biodiversity Site

Site Map

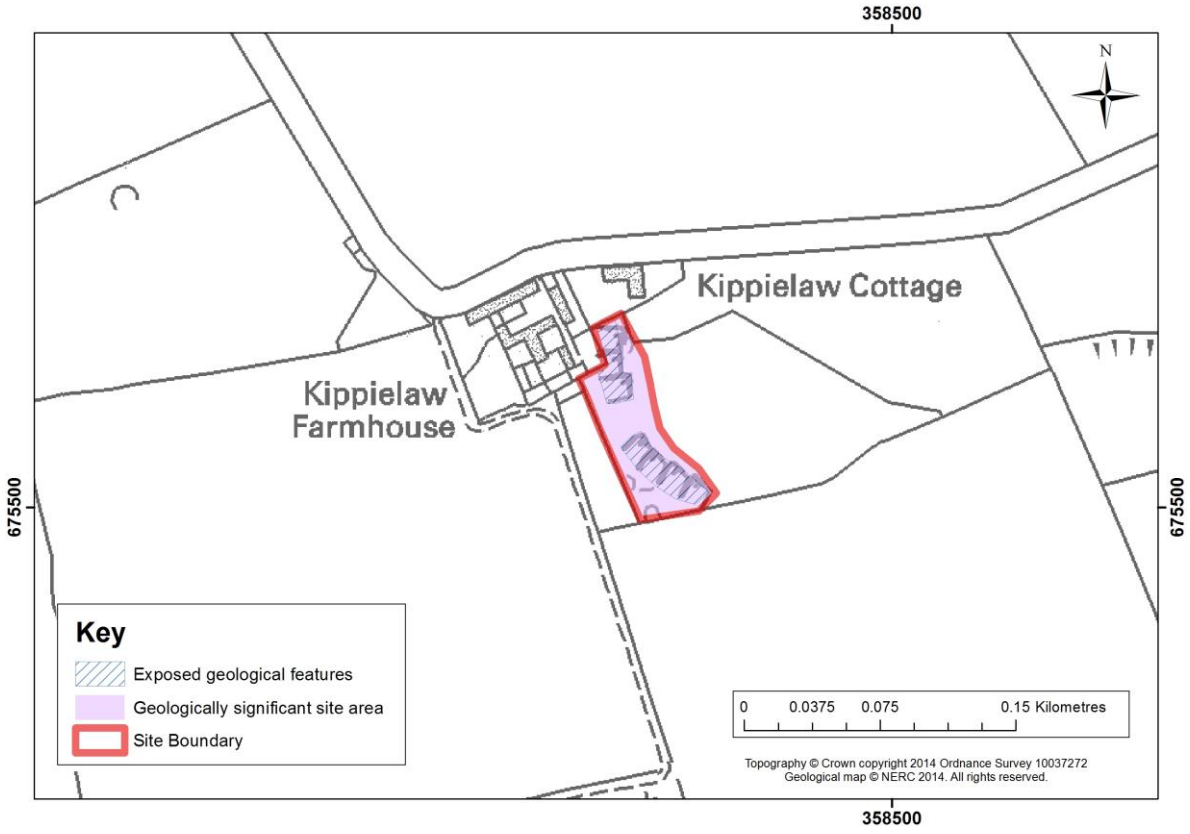


Figure 14: Kippielaw Scarp Location Map. The site boundary has been drawn to include key exposures, and access to the site as well as suitable viewing distance of the natural surfaces (geologically significant area).

Site Description

Background

The Kippielaw Scarp is situated just to the south-east of Kippielaw Farm. The scarp is composed of the 'Dunsapie' type basalt, which is exposed as both a natural section and within an old quarry. The basalt belongs to the Garleton Hills Volcanic Formation. Kippielaw Scarp has good views of the quarried north face of Traprain Law (Photo ELC_9 P1).

Volcanic Rocks

The basalt outcrop is approximately 6 metres high, exposed within an old quarry (Photo ELC_9 P2). The old quarry face reveals the massive central facies of a lava flow of Dunsapie type, a plagioclase-olivine-clinopyroxene-macrophyric basalt. This basalt contains medium-grained (1–4 mm) phenocrysts of lath shaped, creamy plagioclase feldspar, euhedral phenocrysts of augite and browny-red pseudomorphs after olivine, set in a dark gray groundmass (Photo ELC_9 P3). Joints with random orientations cross the quarry face.

Access and Additional Information

Access and parking is gained by asking permission of the residents of Kippielaw Farmhouse and adjoining dwellings. The outcrop is easily accessible except in the summer months where the area is very overgrown with vegetation and there is no clear path. In front of the quarry lies uneven ground (loose rock material and metal covered by grass) and extensive gorse bushes block access to a lot of good faces. This outcrop is mentioned as an excursion within the Lothian Geology guide.

Stratigraphy and Rock Types

Age: Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Plagioclase-olivine-clinopyroxene basalt (Dunsapie Basalt)	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Access is by the minor road from Traprain Farm heading west to Kippielaw Farmhouse. There is a parking bay opposite Kippielaw Farm which is now comprised of the farmhouse and two other dwellings, and the parking bay belongs to one of the dwellings within the Kippielaw Farm. Access to the site is through the courtyard and a gate belonging to Kippielaw Farm – the actual field that the site is located belongs to Traprain Farm. There is a path which leads to the outcrop but this is very overgrown in the summer.
Safety of access	Access to the site is straightforward but the underlying terrain is uneven as the site has become overgrown.
Safety of exposure	Care should be taken and an assessment made of the face before approaching. The face appears quite stable.
Access	Access via farm track and agricultural land
Current condition	Fresh faces of basalt are accessible through heavily vegetated and gorse bush entrance.
Current conflicting activities	None
Restricting conditions	Overgrown vegetation
Nature of exposure	Outcrop forms part of an escarpment and old quarry.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	No known association

Aesthetic landscape	Good view of the north facing side of Traprain Law and quarry
History of Earth Sciences	No known association
Economic geology	Unknown what the old quarry was used for.

Assessment of Site: GeoScientific Merit

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

Site Geoscientific Value

The site comprises an exposure of 'Dunsapie' type basalt, a plagioclase-olivine-clinopyroxene-macroporphyritic basalt, allowing a study of the petrology and mineralogy, and an interpretation of the lavas erupting during the Carboniferous in the local area.

Kippielaw provides a poor example of a Carboniferous basalt lava flow with local significance.

Assessment of Site: Current Site Value

Community	The site is not well known or visited often apart from the local farmer or residents.
Education	The site represents clean faces of which to examine the mineralogy of the 'Dunsapie' type basalt. This site may be a **good locality for educational fieldwork** related to the volcanism related to the Carboniferous in Scotland, but similar basalts are exposed at North Berwick Shore.

Assessment of Site: Fragility and potential use of the site

Fragility	Natural overgrowth and erosion and weathering of feature.
Potential use	School education, higher/further education

Geodiversity Summary

The site exposes clean faces of 'Dunsapie' type basalt, a plagioclase-olivine-clinopyroxene basalt belonging to the Garleton Hills Volcanic Formation. Despite its clean face, access is gained by traversing over heavily vegetated and uneven ground, and the face is partially obscured by gorse vegetation. The site has good views across to Traprain Law.

Site Photos

Photo ELC_9 P1: View of the quarried north-east face of the phonolite laccolith, Traprain Law, a SSSI. Photo is looking south west, taken from Kippielaw Scarp. © BGS, NERC.

Photo ELC_9 P2: Old quarry within 'Dunsapie' type basalt, exposed in the Kippielaw Scarp. Randomly orientated joints cross the face, and likely formed during uplift and/or erosion of the basalt flow. Photo looking north-east. © BGS, NERC.

Photo ELC_9 P3: Detail of the macroporphyritic basalt, bearing phenocrysts of pseudomorphs after olivine, pyroxene, and feldspar. The rock shown is also partially vesicular – the small, spherical hollows are the remnants of what would have been gas bubbles that became trapped in the basalt as it cooled. © BGS, NERC.

ELC_10: Dirleton Castle

Site Information

Location and Summary Description:

Dirleton Castle is located within the village of Dirleton and is perched on a porphyritic trachyte crag within the grounds. The igneous rock is part of the Garleton Hills Volcanic Formation and was extruded as lava during the Carboniferous age. The ruined castle dates back to the late 13th Century and underwent three phases of building. Due to its elevated position it was ideal for defensive purposes from land and sea.

National Grid Reference: Mid-point: 351616, 683954	**Site type**: • Natural exposure
Site ownership: Historic Scotland	Current use: • Visitor Attraction
Field surveyors: Sarah Arkley and Eileen Callaghan	Current geological designations: None known
Date visited: 14th May 2014	Other designations: Scheduled Ancient Monument, Castle, doocot and boundary wall are Category A listed buildings.

Site Map

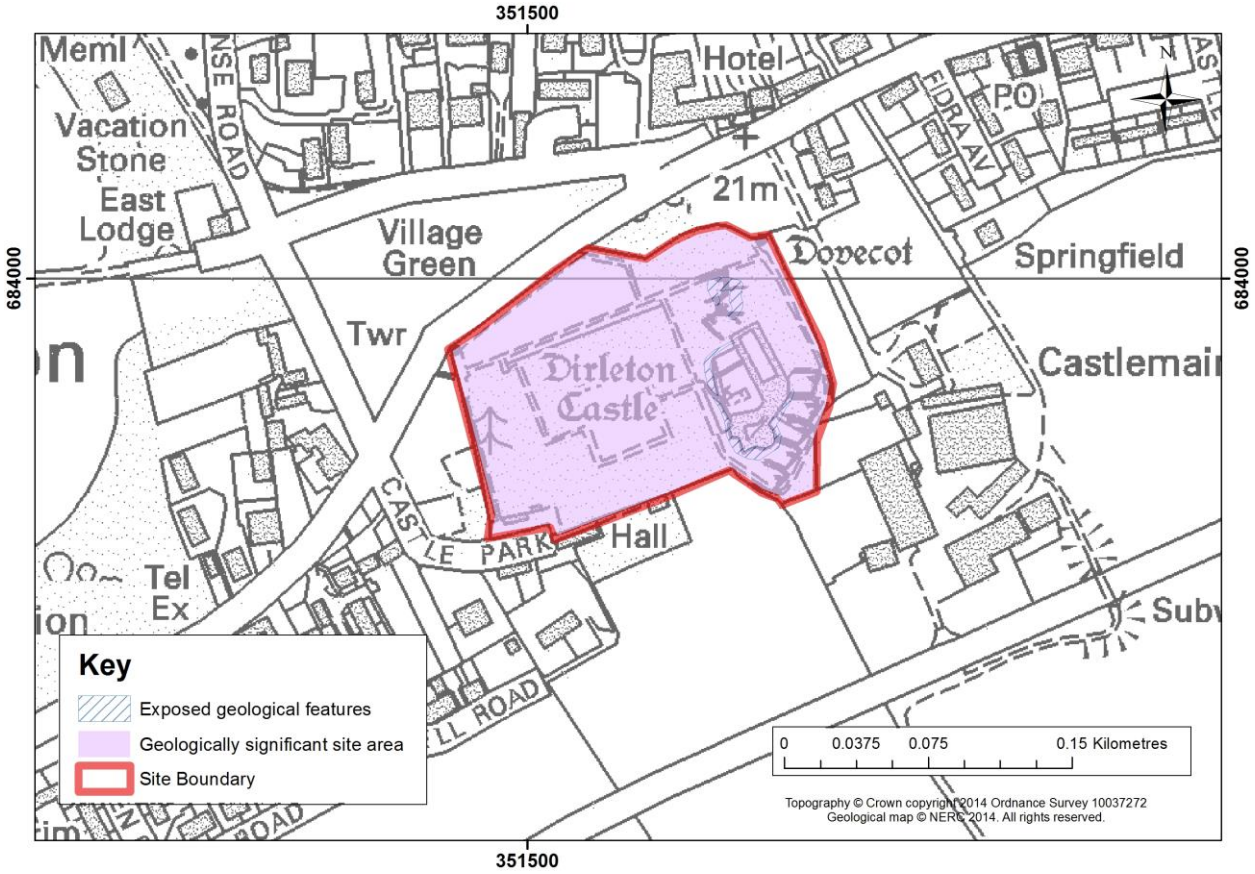


Figure 15: Dirleton Castle Location Map. The site boundary is drawn to include key exposures, access to the castle and grounds and coincides with the area of the Scheduled Ancient Monument. The castle itself is also considered to be part of the geologically significant area associated with the site.

Site Description

Background

Dirleton Castle lies within the village of Dirleton approximately 2.5kms from the town of North Berwick. The castle stands on an outcrop of porphyritic trachyte, forming part of the Garleton Hills Volcanic Formation (ELC_10 P1). Dirleton Castle is owned by Historic Scotland who charges for entry into the castle and grounds. The castle's strategic position lends to good views of the surrounding countryside and coast.

Igneous Rocks

The red-purple stained, fine-grained trachyte lava exposed at Dirleton Castle is typical of the trachyte lavas which form the Garleton Hills. The north-west corner of the exposure is up to 5 metres in height displaying large jointed faces (Photo ELC_10 P2). The porphyritic trachyte is purplish in colour, with feldspar phenocrysts up to 5mm in size, (Photo ELC_10 P3) and weathered out vesicles. The exposure to the west and south is blockier in appearance, (ELC_10 P4), again purplish in colour with vesicles (ELC_10 P5).

Concentric ring structures (ELC_10 P6) are seen within the trachyte at the western edge of the exposure. These structures, exposed by weathering, may be original features which may have developed through cooling of the lavas.

Access and Additional Information

Dirleton Castle is easily accessible as it is owned and managed by Historic Scotland. It is open throughout the year and opening times can be found on their website. There is a charge for entry into the castle and gardens.

The castle is constructed of igneous blocks, probably locally derived and dressed in sandstone that may have been derived from quarries near the nearby village of Gullane (ELC_10 P7).

Stratigraphy and Rock Types

Age: Lower Carboniferous	Formation: Garleton Hills Volcanic Formation
Rock type: Porphyritic trachyte	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Located within the village of Dirleton, the castle is easily accessed by car and bus. The A198 passes Dirleton village. There is parking beside the castle and also public toilets.
Safety of access	The site is easily accessible with paths throughout the site.
Safety of exposure	Some of the faces exposed are up to 5 metres in height. Where the rock is weathered and fractured care should be taken when observing the exposure close up. There are signs prohibiting climbing on the rocks.
Access	Historic Scotland charge an admission fee for entry to the castle and grounds.
Current condition	The rock is well exposed and free from vegetation. The surfaces are weathered but on close inspection fractures, structural features and composition of the rock can be seen.
Current conflicting activities	Tourist attraction.
Restricting conditions	Opening times of the site.
Nature of exposure	Natural exposure

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	Dirleton Castle dates back to the 13th Century and has been partially destroyed, rebuilt and extended over the following 400 years (ELC10_P8). The gardens that surround the castle date from the late 19th and early 20th centuries. The Nisbet family passed the castle and gardens into state care in the 1920's.
Aesthetic landscape	Historic building sited on a natural exposure of rock.
History of Earth Sciences	John Muir Way passes through Dirleton
Economic geology	The castle building stone may have been brought from Gullane Quarry.

Assessment of Site: GeoScientific Merit

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

Site Geoscientific Value

The rock on which Dirleton Castle is situated is an excellent exposure of porphyritic trachyte of the Garleton Hills Volcanic Formation. The rock is well exposed, free from vegetation and easily accessible. The castle and grounds are managed by Historic Scotland which charge entry into the site.

Dirleton Castle and crag provides an excellent example of Carboniferous extrusive volcanic rock, with local significance. The overall site has important historical associations.

Assessment of Site: Current site usage	
Community	The site is visited throughout the year; figures show it had 24,512 visitors in 2013–14 (figures from the Historic Scotland website).
Education	The site at present is probably used for historical relevance rather than earth science education.

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering; activities relating to heritage preservation that may obscure the rock features.
Potential use	On site interpretation. At present there are interpretation boards with relation to the history of the castle (ELC_10 P8), a paragraph of the rock outcrop could be added to these. The John Muir Way passes through Dirleton, information pertaining to the outcrop could be added to their literature or an interpretation board could be erected on the village green.

Geodiversity Summary

The main value of this site is the historical association that Dirleton Castle has within East Lothian. There are other exposures of porphyritic trachyte at nearby Craigs Quarry (ELC_11), Peppercraig Quarry (ELC_3) in Haddington, and Yellowcraig Coast (ELC_6). The exposure at Dirleton Castle provides one of the best exposures of porphyritic trachyte across East Lothian, with direct historical associations.

Site Photos

Photo ELC_10 P1: View of Dirleton Castle, built upon a crag of porphyritic trachyte .© BGS, NERC.

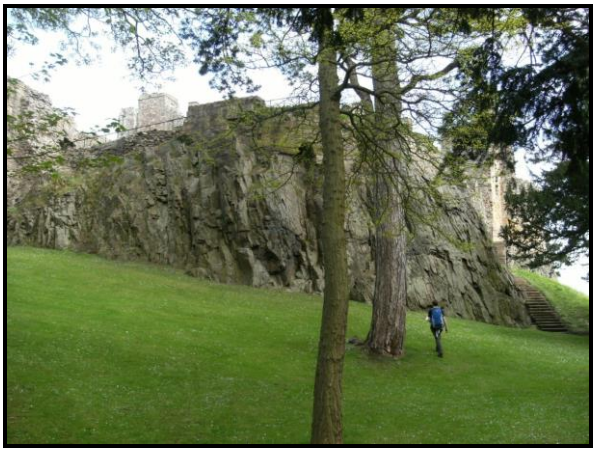


Photo ELC_10 P2: Good exposure of the trachyte is found within crags at the north-west corner of the site. © BGS, NERC.

Photo ELC_10 P3: Feldspar phenocrysts within the trachyte, measuring up to 5mm in size. © BGS, NERC.

Photo ELC_10 P4: The trachyte is more blocky in appearance to the south and west of the site. © BGS, NERC.

Photo ELC_10 P5: Weathered out feldspars and vesicles (formed by gas bubbles within the laval) give the trachyte a pockmarked appearance in places. © BGS, NERC.

Photo ELC_10 P6: Structural features within the trachyte, such as these concentric rings, are exposed through weathering. It is thought these ellipsoids were developed during the cooling process of the lava.© BGS, NERC

Photo ELC_10 P7: Blocks of igneous rock (dark reddish brown) have been used in the construction of the castle; the castle has then been dressed by the paler yellow/white sandstone blocks which are seen weathering in the photograph. © BGS, NERC.

Photo ELC_10 P8: Existing Interpretation panel describing the history of Dirleton Castle. Additional information could be provided on interpretation boards like these to describe the bedrock foundations on which the castle is built. © BGS, NERC.

ELC_11: Craigs Quarry, Dirleton

Site Information

Location and Summary Description:

Craigs Quarry (infilled since the 1970's) is located to the west of the village of Dirleton, situated off the A198. The site is now known as Craigs Plantation and is used by an archery club. The plantation contains small out crops of porphyritic trachyte, belonging to the Garleton Hills Volcanic Formation and of Carboniferous age.

National Grid Reference: Mid-point: 350852, 683556	**Site type**: • Disused quarry
Site ownership: Archerfield Estate	Current use: Tree plantation and archery range (STAFAA)
Field surveyors: Sarah Arkley and Eileen Callaghan	Current geological designations: None known
Date visited: 14th May 2014	Other designations: Ancient Woodland site (Dirleton)

Site Map

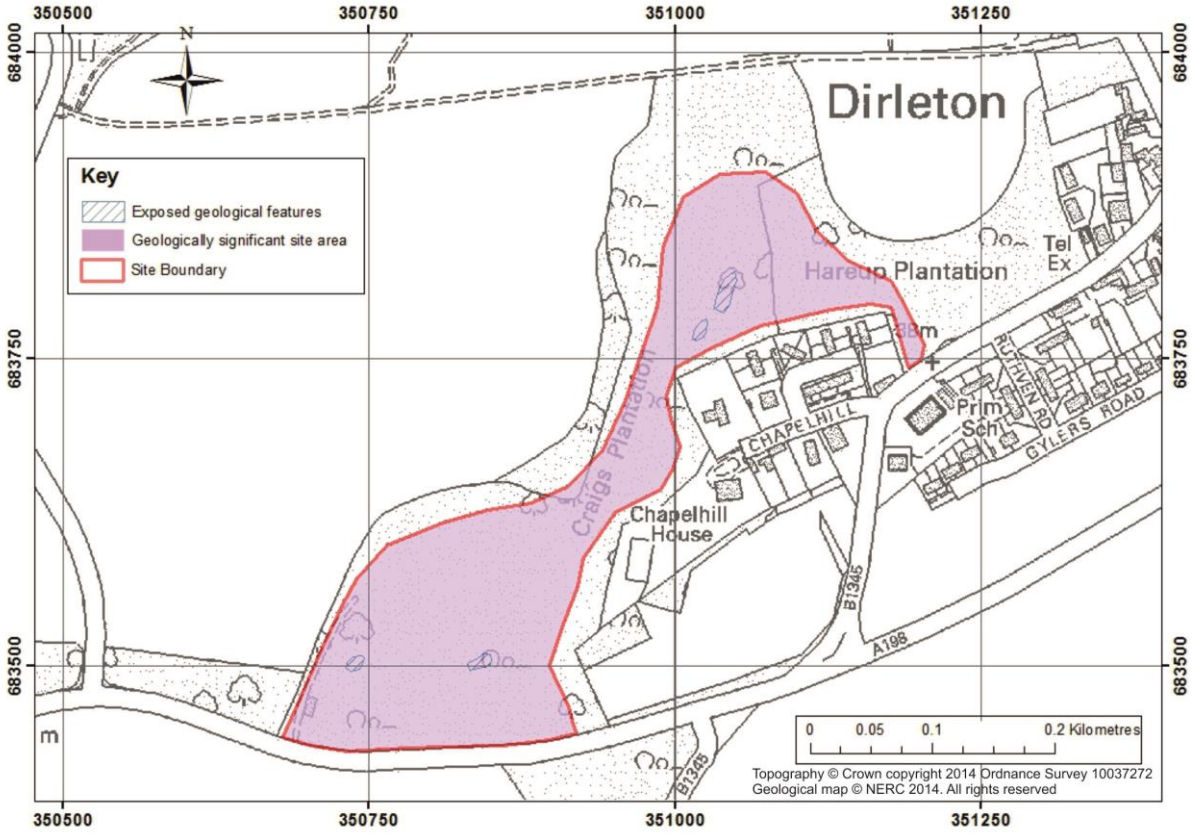


Figure 16: Craigs Quarry Location Map. The site boundary includes small areas of rock exposure, with a larger geologically significant area that incorporates the location of the old Craigs Quarry, and access paths to the site.

Site Description

Background

Craigs Quarry was abandoned at the beginning of the 20th Century and has been filled in over the years. There is no evidence of the quarry now but there are rock exposures to the north east of the original quarry. The rocks exposed within the site are composed of porphyritic trachyte, a lava flow within the Garleton Hills Volcanic Formation. Historically, rock from this quarry would have been extracted for road metal, but as the rock was an inferior quality to similar rock quarried elsewhere, the quarry was abandoned c.1900.

Igneous Rocks

The porphyritic trachyte exposed at the site is part of the trachytic lava and tuff sequence which comprise the Bangley Member (the uppermost or youngest part of the Garleton Hills Volcanic Formation). The exposures of porphyritic trachyte at the site vary in height from 1 – 5 metres (ELC_11 P1), and are fractured and weathered (ELC_11 P2). Clean faces of the porphyritic trachyte show 3 -4 mm cream/greenish coloured feldspar phenocrysts, which have likely been altered to clay (ELC_11 P3).

Access and Additional Information

Craigs Plantation can be accessed via a gate from the A198. There are signs warning that the area is used as an archery target area (ELC_11 P4), and there are paths throughout the planation between targets. The ground is uneven and can be overgrown in places. The John Muir Way crosses to the north of Craigs Plantation and may provide access from the north.

Stratigraphy and Rock Types

Age: Lower Carboniferous	Formation: Garleton Hills Volcanic Formation (Bangley Member)
Rock type: Porphyritic trachyte	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	There is parking in Dirleton and a short walk, approximately 100 metres along the pavement on the A198 to the site entrance.
Safety of access	Care to be taken when walking along the road side. The infilled quarry and surrounding plantation is uneven under foot but paths make the exposures accessible.
Safety of exposure	The exposures are between 1-5 metres in height and in some places the rock is very weathered and fractured. Care should be taken when observing the exposure close-up.
Access	The Scottish Target and Field Archery Association use this site and there is signage to indicate whether the range is in use or not. There is also a contact telephone number displayed (ELC_11 P4)
Current condition	The quarry has been infilled and there is no real indication to deduce that this was a working quarry. The best exposures are further into the plantation away from the road. These can be accessed but in some places the area is overgrown and has been used as a rubbish tip.
Current conflicting activities	Castlefield Archery Club
Restricting conditions	The archery range being in use.
Nature of exposure	Rock faces.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological &	Archaeological digs have revealed a fort at this location with walls

literary associations	estimated to be of 1st Century BC in age. Craigs Quarry is shown in OS historic maps of 1854 but by 1895 the quarry is only shown as rock outcrop and not by name.
Aesthetic landscape	Location of Craigs Quarry on the outskirts of Dirleton, revealing the underlying geology
History of Earth Sciences	No known association
Economic geology	Road metal

Assessment of Site: GeoScientific Merit

	Rarity	Quality	Literature/Collections	Primary interest
Lithostratigraphy				
Sedimentology				
Igneous/Mineral/ Metamorphic Geology	Local	Moderately Good	(Clough et al., 1910)	X
Structural Geology				
Palaeontology				
Geomorphology				

Site Geoscientific Value

The site surrounding Craigs Quarry contains sparse exposures of the porphyritic trachyte belonging to the Garleton Hills Volcanic Formation. Exposures of this rock type are also found at nearby Dirleton Castle (ELC_10), Peppercraig Quarry (ELC_3), and Yellowcraigs (ELC_6).

This site is a moderately good example of a porphyritic trachyte lava flow, indicative of Carboniferous volcanic activity, with local significance.

Assessment of Site: Current site usage

Community	The site is frequented members of the Castlefield Archery Club.
Education	At present the site is rarely visited. Given the quality of other sites in East Lothian, this site has limited educational potential

Assessment of Site: Fragility and potential use of the site

Fragility	Weathering/erosion, natural overgrowth.
Potential use	Limited potential

Geodiversity Summary

The site comprises good exposures of porphyritic trachyte, an extrusive volcanic rock, nearby the village of Dirleton. The site is used at present by an archery club which may cause conflicting access to the site. The best exposures are in the north of the site area. This site represents the best outcrop of porphyritic trachyte within East Lothian: other sites within this report have outcrops of this rock but do not have as good access or faces to examine.

Site Photos

Photo ELC_11 P1: Fractured porphyritic trachyte exposure within the Craigs Plantation. © BGS, NERC.

Photo ELC_11 P2: Exposure of the porphyritic trachyte displaying fissile weathering, creating the illusion of bedding. This type of weathering is typically found near the top of a lava flow. © BGS, NERC.

Photo ELC_11 P3: Close up of the porphyritic trachyte showing greenish-cream coloured feldspar phenocrysts. © BGS, NERC.

Photo ELC_11 P5: Signage within the site © BGS, NERC.

ELC_12: Peppercraig Quarry, Haddington

Site Information

Location and Summary Description:
The site comprises a small quarry located immediately north of the town of Haddington. The igneous rock of Carboniferous age extracted from the site was reportedly used to construct many of Haddington's stone buildings. Now largely infilled, the quarry contains a small industrial park but exposures of the porphyritic trachyte remain in the back walls.

National Grid Reference: Mid-point: 350800,674500	**Site type**: • Artificial quarry works
Site ownership: Not known – Guy's Garage forms part of the site.	**Current use**: • Disused • Industrial land
Field surveyors: Sarah Arkley & Rachael Ellen	**Current geological designations**: None known
Date visited: 16th April, 2014	**Other designations**: None known

Site Map

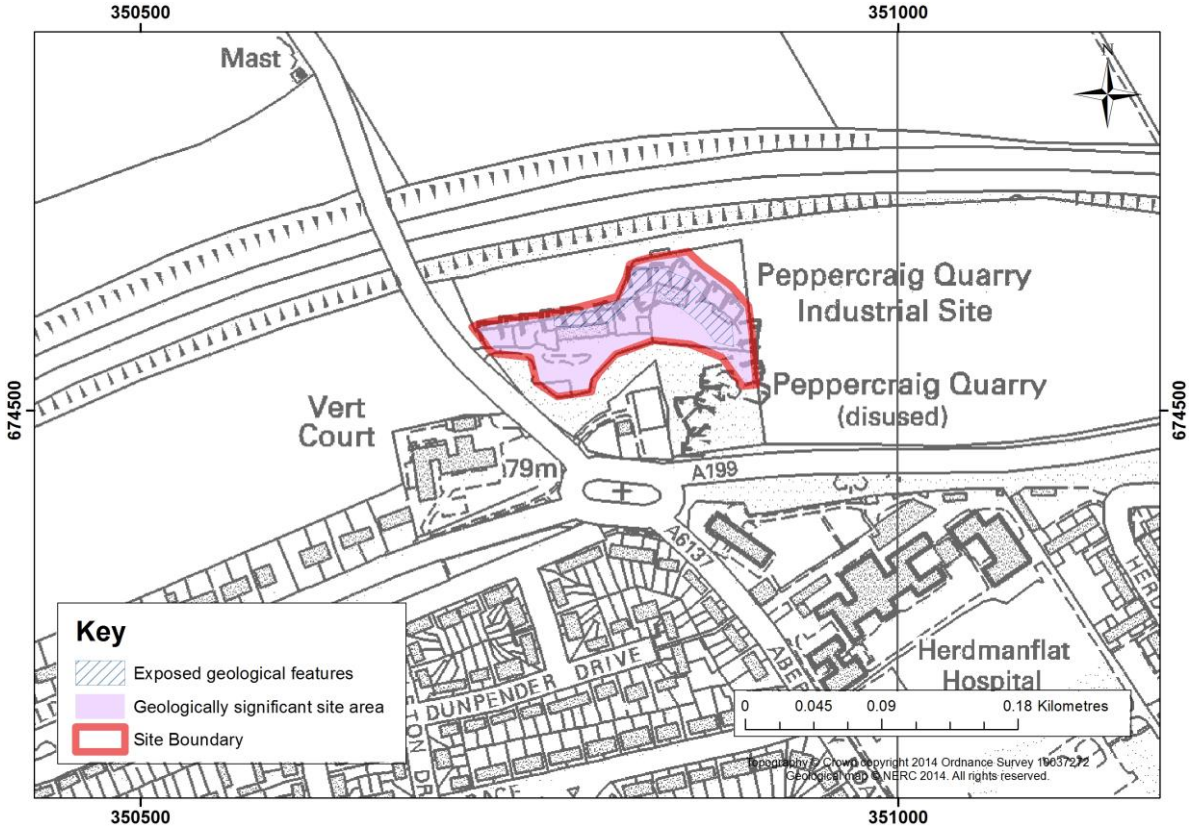


Figure 17: Peppercraig Quarry Location Map. The site boundary includes the original extent of the quarry, which is historically and geologically significant due to its importance in providing building stone to the town of Haddington. Exposed rock is highlighted by blue hatched areas.

Site Description

Background

Peppercraig Quarry lies on the northern outskirts of the town of Haddington, between the A1 to the north and the A199 to the south. The quarry is composed of a porphyritic trachyte, an ancient lava flow belonging to the Garleton Hills Volcanic Formation. Historically, rock from this quarry has been extracted for the construction of many of Haddington's stone buildings (ELC_12 P1, P2, P3) and for road metal. Most of the quarry has been infilled, and few exposures remain throughout the extent of the old quarry. The uppermost 1–2 m of the quarry face remains exposed just to the east of a car servicing garage, at the north-east of the site which, at time of visit, was a building site (ELC_12 P4, P5). Contractors there revealed that recent boreholes showed 10 m of 'fill' material (presumable quarry infill) before going through at least 6 m of porphyritic trachyte. The contractors also advised that after construction the quarry walls would remain visible.

Volcanic Rocks

The porphyritic trachyte exposed at the site is part of the trachytic lava and tuff sequence which comprise the Bangley Member (the uppermost or youngest part of the Garleton Hills Volcanic Formation). The porphyritic trachyte exposed at the site is part of a massive lava flow (ELC_12 P6), displaying large, up to 1 cm sized creamy-brown feldspar phenocrysts set in a fine grained dark grey groundmass (ELC_12 P7). The rock is highly weathered at the surface (ELC_12 P8), evidenced by intense fracturing at the top of exposures and by replacement of feldspar phenocrysts to clay. Contractors on site advised the porphyritic trachyte at 6 m depth within the borehole did not display this weathering, and was instead a very solid and cohesive rock.

Access and Additional Information

The site is accessed just north of the roundabout linking the A6137 and A199 in Haddington. The Peppercraig Industrial Estate has a car garage within it, and parking is possible nearby there without restricting access. At the time of visit, building contractors were actively on site, with permission required to gain entry. Once building work is complete the rock face will still be accessible, although it will be fenced off, impeding access to the exposure.

Stratigraphy and Rock Types

Age: Lower Carboniferous	Formation: Garleton Hills Volcanic Formation (Bangley Member)
Rock type: Porphyritic trachyte	

Assessment of Site: Access and Safety

Aspect	Description
Road access and parking	Located immediately north of Haddington, between the A1 and the A199, there is good road access directly into the site. Turn off the A6137, down a narrow metalled road into the Peppercraig Quarry Industrial Park, parking for a few cars can be found within the estate opposite a car servicing centre. Access to the quarry face is more difficult as it lies behind small industrial units/plots which are largely fenced off.
Safety of access	The Quarry is largely infilled, floored by a concrete or rubble surface
Safety of exposure	The remaining quarry face is low, less than 2m high, so there is little risk of material falling from a height, however, the rock is very weathered/fractured in places so care should be taken when observing the exposure close-up.
Access	The quarry is now an industrial park, most of the quarry face area is fenced off.
Current condition	Exposures are from the uppermost part of the former quarry and display weathered (rather than fresh) exposures of the trachyte which was worked. Annual vegetation growth may obscure the quarry face to some extent in the summer months.

Current conflicting activities	None known, although any of the businesses located within the site could develop right up to the face or obscure it with stored materials.
Restricting conditions	Due to the present industrial use of the site, gaining hands-on access to the quarry face may be difficult.
Nature of exposure	Vertical quarry faces

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	Historical Ordnance Survey maps record the quarry in existence as early as 1855; it is then shown on the 1895, 1908 and 1938 maps and assumed to be active during this time. Although a reference in The Geology of East Lothian publication (1910) indicates that the quarry was no longer used at that time.
Aesthetic landscape	Old quarry on the outskirts of Haddington, revealing the underlying geology
History of Earth Sciences	None known
Economic geology	Former building stone and road metal quarry.

Assessment of Site: GeoScientific Merit

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

Site Geoscientific Value

The site provides access to poor quality exposures of porphyritic trachyte within the Peppercraig Quarry. The biggest attraction of this site is its historical connection to the building stones of Haddington, therefore despite having a low rating in rarity and quality this site is important to the heritage of East Lothian.

Peppercraig Quarry provides a poor example of Carboniferous extrusive volcanic rock, with local significance. However, the overall site has important historical associations with the building stones of Haddington.

Assessment of Site: Current site usage

Community	Quarry is located on the outskirts of Haddington and has been redeveloped as a small industrial park with 3 or 4 local businesses occupying the site. The site is probably only frequented by proprietors and clients of these businesses and it is likely that quarry is currently rarely or never visited for its geological interest or historical/economic associations.

Education	As the rock extracted from the quarry was used to construct many of Haddington's stone buildings, the site should be of interest to **any local school or group investigating the history of the town.**

Assessment of Site: Fragility and potential use of the site	
Fragility	Natural overgrowth, Likelihood of development
Potential use	Include within local history information/leaflets)

Geodiversity Summary

The main value of this site is its economic/cultural association with Haddington. There are numerous exposures and even quarries in the local area revealing the same porphyritic trachyte seen here, However the local town of Haddington is recorded to have been largely built of the igneous material extracted from Peppercraig Quarry. Haddington is one of the main towns in East Lothian and this link gives the site increased significance.

Site Photos

Photo ELC_12 P1: The building which houses the John Gray Centre in the middle of Haddington contains blocks of porphyritic trachyte, probably from Peppercraig Quarry. © BGS, NERC.

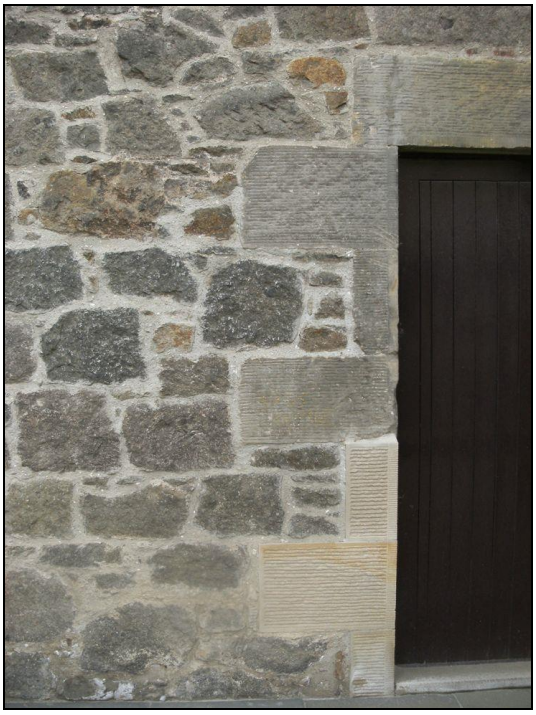


Photo ELC_12 P2: Detail of part of the north facing wall of the John Gray Centre, displaying irregular shaped porphyritic trachyte blocks making up most of the wall with shaped sandstone blocks forming the door surround. © BGS, NERC.

Photo ELC_12 P3: Close-up of porphyritic trachyte blocks used in the John Gray Centre. Note the large pale-coloured crystals (phenocrysts) scattered within a fine-grained dark green/purple groundmass. Typical of the material seen in Peppercraigs Quarry. © BGS, NERC.

Photo ELC_12 P4: Small industrial park which lies within the former Peppercraig Quarry. © BGS, NERC.

Photo ELC_12 P5: The uppermost 1-2 m of the quarry face is all that remains exposed following the infilling of the quarry. Although exposures are fairly clean they are generally fenced off and not easily accessible. Quarry face in the western part of the site. © BGS, NERC.

Photo ELC_12 P6: Ongoing work in the eastern part of the site has cleared material away the quarry face. Although the face will be left exposed, the floor is to be concreted and a fence constructed around the plot, impeding/preventing access to the exposure. Quarry face in the central part of the site. © BGS, NERC.

Photo ELC_12 P7: Detail of the uppermost part of the quarry face showing the increasingly weathered nature of the igneous rocks towards the natural surface. © BGS, NERC.

Photo ELC_12 P8: Close up of the porphyritic trachyte which was extracted from the quarry and used to construct many of Haddington's stone buildings. © BGS, NERC.

ELC_13: Gullane Shore

Site Information

Location and Summary Description:
The site comprises a1.5 km section of coastline located to the west of the town of Gullane between Gullane Point and Bleaching Rocks. Cliff and coastal platform sections along the coast at the site expose sedimentary strata of the Dinantian age (early Carboniferous) Gullane Formation and younger intrusive igneous rocks.

National Grid Reference: Mid-point: 346590, 683094 West end: 346152, 682728 East end: 347316, 683158	**Site type**: • Natural section/exposure • Natural landform • Natural view
Site ownership: Crown	Current use: Open Country
Field surveyors: Sarah Arkley, Katie Whitbread	Current geological designations: Firth of Forth SSSI
Date visited: 11th June 2014	Other designations: Firth of Forth SPA, Ramsar, Aberlady Bay Local Nature Reserve

Site Map

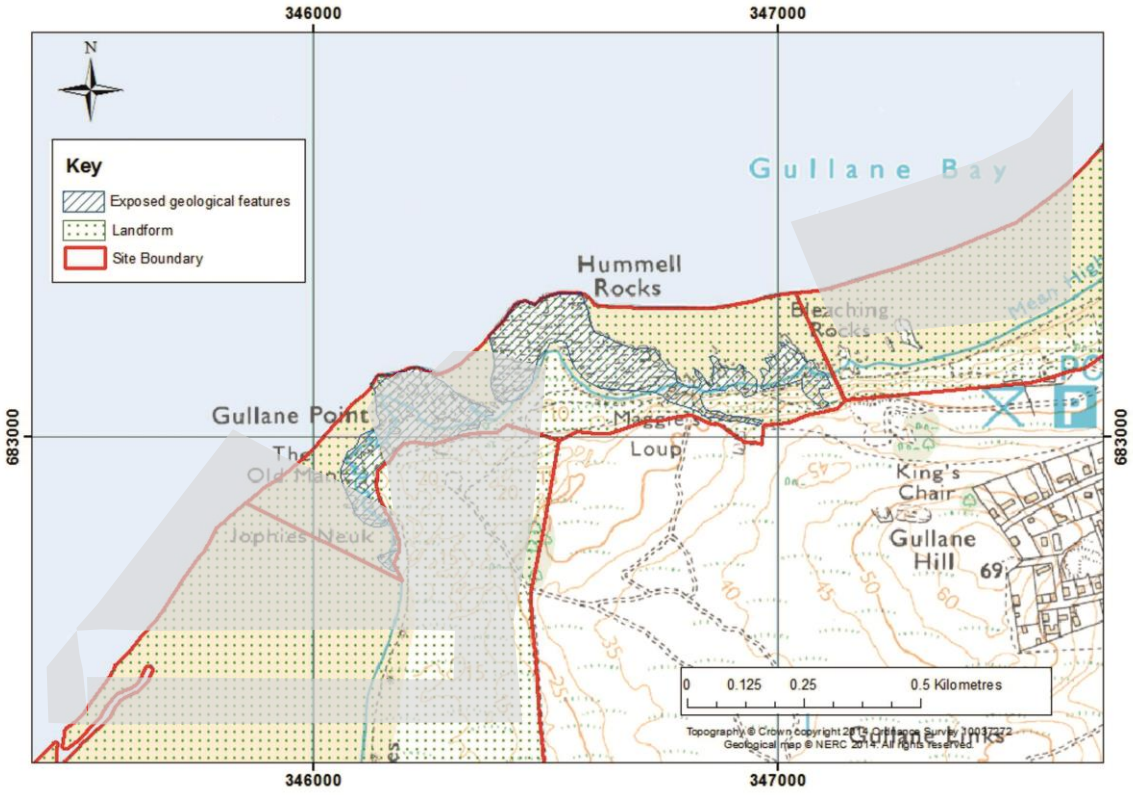


Figure 18: Gullane Shore Location Map. The site area comprises bedrock exposures in shore platforms and coastal landforms including inlets and areas of beach in the immediate vicinity of the main rock outcrops**,** The exact area of bedrock exposure is likely to vary in time due to changes in the beach morphology. This site is adjacent to the Aberlady Bay Site (ELC_30) and Gullane Bents Site (ELC_29), here greyed out.

Site Description

Background and site area

Gullane Point is located west of the town of Gullane, forming a broad peninsular with the wide beach of Gullane Sands to the east. Between Gullane Point and Gullane Bents to the west there is a 1.5 km shore section containing rock platform and cliff exposures. Sandstone exposed in these shore sections was formerly quarried at three sites located close to the coast near Gullane Bents. These quarries are now infilled or overgrown and no rock is exposed.

Sedimentary Rocks

The sedimentary rocks exposed in the shore and coastal cliffs at Gullane from part of the Gullane Formation of the Strathclyde Group (formerly called the Calciferous Sandstone Measures). The Gullane Formation comprises a cyclic sequence of sandstone, siltstone and mudstone containing ironstone nodules, conglomerate beds and some thin seatearths.

In the west of the section, just to the east of Gullane Point, a variety of well-exposed sedimentary features indicative of shallow marine or estuarine and fluvial environments are visible in the sandstone units. Tabular sand beds 0.2 – 1.5 m thick are common in the west of the section near Gullane Point and are interbedded with some siltstone beds. These beds commonly contain abundant trace fossils including prominent beds dominated by 2 – 3 cm diameter, 10 – 20 cm long vertical burrows (Diplocraterion), and/ or dense networks of finer irregular burrows. The fine irregular burrows also occur in siltstone beds where they are seen as casts of sandstone.

In places, the tabular sandstone and siltstone beds are cut by medium- to coarse-grained, erosional channel sands with abundant organic rich laminae towards the base and fine lystric bedding formed in laterally-accreting channel bars defined by fining-up sediment packages 1 – 2 cm thick. Conglomerate beds with erosional bases also occur in places. These beds comprise a clast-supported, sub-angular to sub-rounded gravel of quartz, quartzite, red mudstone and other lithic clasts in a coarse sandy matrix and appear to fine upwards.

Complex soft sediment deformation in some of the thicker sandstone beds indicates mass flows of sand during or soon after deposition. A particularly good example is seen in an approximately 10 m thick massive sandstone bed exposed in a vertical cliff at Bleaching Rocks. At the base of the deformed sandstone is a sharp contact with a 0.5 m thick laminated pinkish-sandstone that thins to the east to c. 0.1 m thick. It is possible this sandstone may be a liquified ‘sliding layer’ between the deforming sand body and the underlying siltstone with laminations caused by ‘streaking’ out of the strata.

In the centre of the section at Hummell Rocks, dark grey, shaly mudstone with abundant large bark fragments visible in the flat surfaces of the rock platform. Bark textures include irregular linear ridges, and a regular pattern of slightly tear-drop shaped marks consistent with Lycopod bark.

Igneous Rocks

The sedimentary strata are intruded by igneous rocks (Anlacime-Gabbro) of the Lower Gullane Head Sill and Upper Gullane Head Sill (Midland Valley Carboniferous to early Permian Alkaline Basic Sill Suite). Due to the westerly dip of the strata, the upper sill is exposed in the rock platform to the west of the section at Gullane Point, and the lower sill crops out to the east at Hummell Rocks and in the cliffs at Corby Craigs.

The Anlacime-Gabbro (formerly called Teschenite) is a medium to coarse-grained crystalline rock with a greenish-grey colour. In many areas 2 – 3 mm diameter abundant Analcime phenocrysts are present and altered to a rust-red colour. At Gullane Point, a complex zone occurs in centre of upper sill with paler igneous rock apparently intruded into the magma forming the analcime-gabbro. Abundant mineralised hydrothermal veins occur in this area.

The lower contact of the upper sill with the underlying sedimentary rocks can be seen in the rock platform near Gullane Point at low tide. The contact between the lower sill and the underlying sandstone can be seen in the base of the coastal cliff at Maggie’s Loup. Large polygonal cooling joints are developed in the upper sill in the region of The Old Man west of Gullane Point, and in the lower sill at Corby Craigs.

Structural Geology

The sedimentary strata tend to dip shallowly to the west or south-west but are broadly folded to the east of Hummell Rocks. Several minor faults bisect the strata near Ironstone Cove and to the east of

Hummel Rocks. These faults are exposed in places as zones of densely fractured rocks.

Faults and fractures within the igneous sills are commonly mineralised with calcite and well-developed slickensides can be seen in places.

Quaternary Deposits and Landforms

The coastal rock exposures comprise erosional cliffs and shore platforms interspersed with beaches in small bays. At the promontory of Hummell Rocks, a section in the back of a small bay exposes 1 to 1.5 m of raised beach deposits overlying bedrock. The raised beach deposit consists of c. 0.3 – 0.4 m of very shelly sand with fine gravel, overlain by well-rounded gravel and cobbles in a sandy matrix. The raised beach deposit lies at an elevation of 2 – 3 m above the high tide level and continues further inland where it is overlain by up to 4 m of blown-sand deposits. The raised beaches and overlying dunes to the west, at Gullane Point, and south are included within the adjacent Aberlady Bay geomorphological site (ELC_30).

Blown sand (dunes) overlie bedrock, marine beach or raised beach deposits along the landward edge of the coast from Gullane Sands to Gullane Bents. The sands flats along the shore of Gullane Bay which extend to the east into the area of the Gullane Bents geomorphological site (ELC_29) are an part of the beach-dune sediment system at Gullane Bents.

Access and Additional Information

There is good access to the coast via footpaths from the public car park at Gullane Bents. Access along the coast is facilitated by a network of footpaths through the dunes.

Stratigraphy and Rock Types	
Age: Dinantian	Formation: Gullane Formation (Strathclyde Group)
Rock type: Sandstone, siltstone, mudstone with minor ironstone, seatearths, coal and limestone	
Age: Carboniferous to early Permian	Formation: Upper and Lower Gullane Head sills
Rock type: Analcime-Gabbro	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	There is good access to the site via a public car park at Gullane Bents. Toilet facilities are also provided near the car park. Access to the site can also be made from a parking area approximately 1 km north-east of Aberlady.
Safety of access	Footpaths provide good access along the coast at high or low tide and there are rock exposures above the high-tide level at many points. Access to coastal platforms and the base of some cliff sections is restricted at high tide. Visitors should be aware of tide times and access routes when visiting the site.
Safety of exposure	The cliffs appear generally stable, but care should always be taken beneath cliffs, particularly in over-hanging areas. Care should also be taken at cliff tops. Rocky coastal platforms and boulder-strewn areas can be hazardous and care should be taken in accessing these areas.
Access	Access via the shore and adjacent footpaths
Current condition	Many rock exposures are clean and free of vegetation. However, in the intertidal zone the sedimentary rocks in particular, may be largely covered by barnacles and algae.
Current conflicting activities	There are several golf course located adjacent to parts of the site. The main access paths skirt the edges of the golf course areas. Golf course developments have resulted in landscaping of areas of the dunes.
Restricting conditions	Many of the geological exposures are located within the intertidal range and are not visible at high tide.

Nature of exposure	Vertical cliff sections, intertidal rock platform and beach exposures.

Assessment of Site: Culture, Heritage & Economic Value

Aspect	Description
Historic, archaeological & literary associations	Stone from the quarries at Gullane may have been used in the construction of Dirleton Castle. The quarries are now derelict or infilled and there is no exposure, but the sandstone units are well exposed in the coastal sections.
Aesthetic landscape	Coastal landscape
History of Earth Sciences	Not known
Economic geology	Sandstone was formerly quarried from small pits above the shore near the car park. These areas are now overgrown and there are no exposed rock faces.

Assessment of Site: GeoScientific Merit

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

Site Geoscientific Value

The shore section at Gullane is the type section for the Gullane Formation and is therefore the most important section through this part of the Carboniferous stratigraphy in the region. The site has excellent exposures of a wide range of sedimentological features, including plant and trace fossils, which are indicative of Carboniferous fluvial environments. There are also good exposures of associated intrusive igneous rocks and their contacts with the surrounding sedimentary rocks.

Gullane Shore provides an excellent example of Carboniferous fluvial sedimentology with regional stratigraphic significance.

Assessment of Site: Current site usage

Community	The site is close to the attractive village of Gullane and close to numerous golf courses. Locals and numerous visitors frequent the site for recreation including walking, exercise and water sports.
Education	The site contains a range of clear sedimentological features that would provide a good introduction to Carboniferous depositional processes and environments, and the relationship between sedimentary strata and intrusive igneous deposits. The site has potential for **geosciences research**, and **teaching potential for Higher/Further and School level education**. Use of the site for teaching purposes may be enhanced by **leaflets or online information**. Members of the general public may benefit from **on-site interpretation such as sign boards or a Geo-trail**.

Assessment of Site: Fragility and potential use of the site	
Fragility	Weathering/erosion
Potential use	Research, higher/further and school education, on-site interpretation, geo-trail.

Geodiversity Summary

The site comprises excellent geological features that are well exposed along a shore environment and is readily accessible by well-maintained paths. There are also good local facilities and amenities, and the area is already a prime recreational site. There is considerable potential for developing the geodiversity value of the site by the provision of geological information either on site or online and through engagement with local schools.

Site Photos

Photo ELC_13 P1: View of the Upper Gullane Sill (foreground) and the northern end of Gullane Sands looking south from Gullane Point. © BGS, NERC.

Photo ELC_13 P2: Intrusive igneous rocks of the Upper Gullane Sill at Gullane Point. The rocks have been extensively hydrothermally altered giving them a sandy, rubbly and veined appearance. © BGS, NERC.

Photo ELC_13 P3: Lycopod Bark imprints in black shaly mudstone at Hummell Rocks. © BGS, NERC.

Photo ELC_13 P4: Burrow traces in sandstone at Hummell Rocks. © BGS, NERC.

Photo ELC_13 P5: View of Gullane Bay looking north-east from the Bleaching Rocks. The bedding of the sandstone in the foreground, visible due to iron staining, has been distorted by soft sediment deformation arising from mass flows in the soft, waterlogged sand soon after it was deposited. © BGS, NERC.

ELC_14: Kilspindie Shore

Site Information

Location and Summary Description:
The site comprises a 2.2 km section of coastline located to the north-west of the town of Aberlady between Aberlady Point and Green Craig. This coastal section exposes the boundary between the Clackmannan Group and the Strathclyde Group of the Dinantian age (early Carboniferous). Limestones from both groups are exposed along this coastal section. The Gosford Sill, a younger intrusive igneous rock is also exposed at the western section of the site.

National Grid Reference: Mid-point: 344707, 680205 South-west end: 344694, 679255 East-end: 345723, 680493	**Site type**: • Natural section/exposure • Natural landform • Natural view
Site ownership: Crown	Current use: Open Country, edge of golf courses
Field surveyors: Rachael Ellen and Eileen Callaghan	Current geological designations: Part of Firth of Forth SSSI
Date visited: 26th August 2014	Other designations: Firth of Forth SPA and Ramsar, Aberlady Bay Local Nature Reserve

Site Map

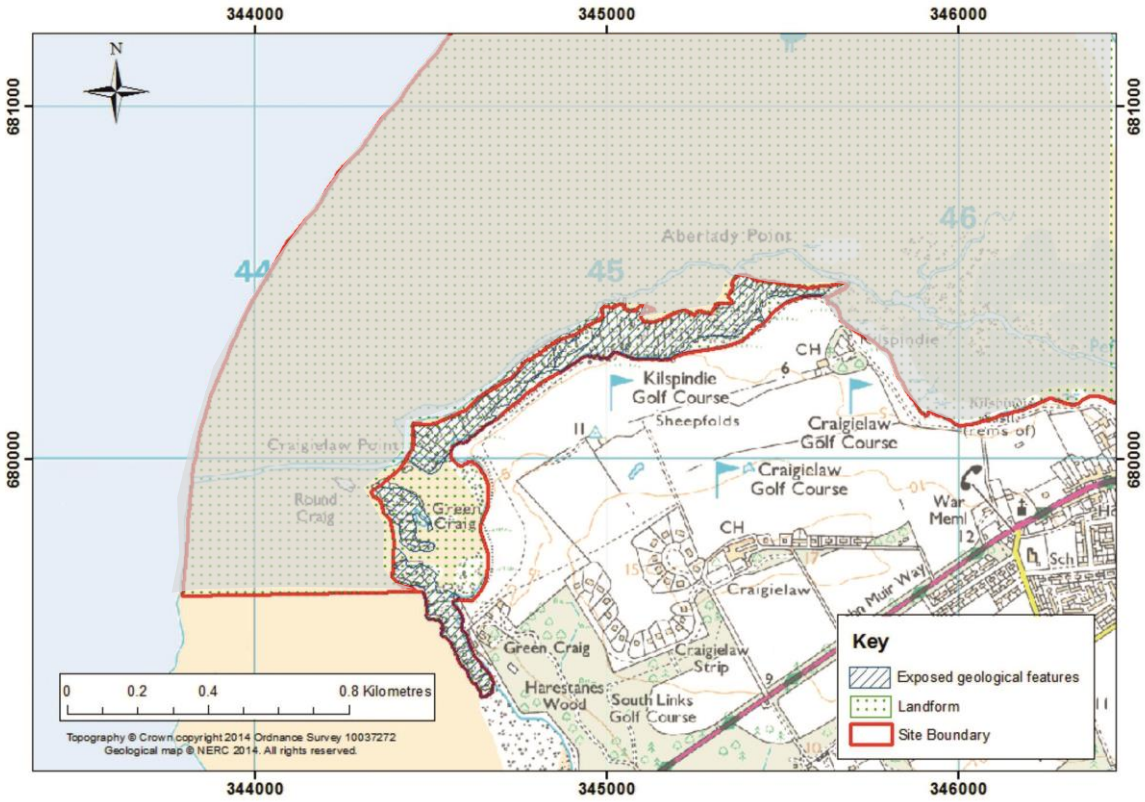


Figure 19: Kilspindie Shore Location Map. The site boundary is drawn to include access along the edge of Kilspindie Golf course, as well as encapsulating local landforms (e.g. beaches) and the key rock exposures. This site is immediately adjacent to the geomorphological Aberlady Bay Site (ELC_30). The local extent of Aberlady Site is shown above as a transparent grey polygon.

Site Description

Background

The Kilspindie Shore site encompasses the western part of Aberlady Bay and the northern area of Gosford Bay. The site is located to the north-west of the town of Aberlady. The 2.2 km section contains limestones of the Clackmannan Group: the Hurlet, the Blackhall and the Inchinnan, as well as the Blackbyre Limestone belonging to the Strathclyde Group. The Gosford Bay Sill which is exposed at the western end of the site is younger in age and is composed of analcime gabbro (dolerite). These exposures are best seen at low tide.

Sedimentary Rocks

The oldest rocks exposed on the Kilspindie Shore site belong to the Strathclyde Group, and are found to the west of the site. These strata comprise siliciclastic rocks of the Aberlady Formation; interbedded pale cream sandstone, siltstones and mudstones with subordinate coal, seatrock, limestones and ironstone. These strata were deposited in a variable environment characterised by fluvial deposition and development of shallow marine conditions. Exposed within the sequences is the Blackbyre Limestone, a pale grey crinoidal argillaceous limestone indicative of a transition to a deeper marine sedimentary environment.

The majority of the sedimentary rocks exposed on the shore at Kilspindie form the lower part of Lower Limestone Formation (Clackmannan Group). The Lower Limestone Formation comprises a cyclic sequence of calcareous mudstones, limestones, sandstones and siltstones containing thin coal seams and some seatearths. The Hurlet Limestone, seen on both the eastern and western part of this shore section marks the boundary between the Clackmannan Group and the underlying Strathclyde Group. The Hurlet Limestone forms a prominent 1 - 5 m bed across the site (ELC_14 P1), with a rubbly, brown weathered top surface. In the eastern part of its exposure, just before Craigielaw Point, the Hurlet Limestone is underlain by a shale bed sitting above a 20 cm thick band of coal (ELC_14 P2). The limestones of the Lower Limestone Formation are fossiliferous, containing crinoids, corals, and brachiopods (ELC_14 P3, P4). At the far west of the site is an exposure of the massive Blackhall Limestone, stratigraphically younger than the Hurlet Limestone. The Blackhall Limestone is up to 8 m thick, massive, and contains crinoid fragments and productid brachiopods (ELC_14 P5, P6). The limestones contain mineral lined vugs of orange/brown calcite ‘teeth’, representing reprecipitated carbonates from dissolution of the limestone.

The cyclic sequences between the limestones are composed of sandstone, siltstone, mudstone and subordinate limestone. The sandstone is quartz-rich, fine to medium grained, with organic patches throughout. There is an indication of bioturbation and rippled features on bedding planes (ELC_14 P7). The siltstones are black/grey, occasionally fossiliferous, very finely bedded and are interbedded with yellowish/brown limestone. The sandstone and interbedded shale is well exposed at a low cliff below a red-tiled hut owned by the Kilspindie Golf Club in the midpoint of the site.

Volcanic Rocks

The Lower Limestone Formation is intruded by the Gosford Bay Sill, an olivine-analcime-gabbro. Exposure of the sill is accessible at high tide, adjacent to the concrete tank blockades sit on the shore (ELC_14 P8).

Quaternary Deposits and Landforms

The shore of the section is littered with glacial erratics of igneous origin, with mafic (dolerite or gabbroic) erratics displaying onion skin weathering (ELC_14 P9). An outlier of sandstone resting on shale forms a sea stack to the north of the site, known as the King’s Kist (ELC_14 P10). Intertidal marine beach deposits form expanses of sand flat that are included within the adjacent Aberlady Bay geomorphological site (ELC_30).

Access and Additional Information

There is good access along the coast line at high tide for most of the site, with access along the side of Kilspindie and Cragielaw golf club possible where the tide is too high. The site is best visited at low tide when one can walk on the shore and see most of the exposures. Parking is advised in Aberlady itself as the car parks near the section belong to Kilspindie Golf Club. The East Lothian Ranger service do not encourage large numbers of visitors along this section of coast due to the diverse bird life along this stretch of shore.

Stratigraphy and Rock Types	
Age: Dinantian	Formation: Lower Limestone Formation
Rock type : Calcareous mudstones, limestones, sandstones, siltstones, coal and ironstone	
Age: Dinantian	Formation: Aberlady Formation (Strathclyde Group)
Rock type: Sandstone, siltstone, mudstone with minor ironstone, seatearths, coal and limestone	
Age: Carboniferous to Permian	Formation: Gosford Bay Sill
Rock type: Analcime-Gabbro	

Assessment of Site: Access and Safety	
Aspect	**Description**
Road access and parking	There is good access to the site. Street parking is available in Aberlady, then following signs on foot to Kilspindie Golf Club or taking a path near the church to Kilspindie Castle. Access to the site can also be made from a parking area at Longniddry Bents (only at low tide) approximately 2 km south west of the western edge of the site. Following the John Muir Way for part of the route.
Safety of access	Faint footpaths provide good access along the edge of the golf course at high or low tide and there are rock exposures above the high-tide level at some points. Access to some sections is restricted at high tide. Visitors should be aware of tide times and access routes when visiting the site.
Safety of exposure	The cliffs appear generally stable, but care should always be taken beneath cliffs, particularly in over-hanging areas. Rocky coastal platforms and boulder-strewn areas can be hazardous and care should be taken in accessing these areas.
Access	Access via the shore and footpaths.
Current condition	Many rock exposures are clean and free of vegetation. However, in the intertidal zone the sedimentary rocks in particular, may be largely covered by barnacles and algae.
Current conflicting activities	There are two golf courses located adjacent to parts of the site. The main access paths skirt the edges of the golf course areas. The area is part of the Aberlady Nature Reserve which may object to encouraging visitors especially during the nesting season.
Restricting conditions	Many of the geological exposures are located within the intertidal range and are not visible at high tide.
Nature of exposure	Intertidal rock platform, beach exposures and small cliff sections.

Assessment of Site: Culture, Heritage & Economic Value	
Aspect	**Description**
Historic, archaeological & literary associations	A quarry was sited near Garlick Rock but there is no historical record of its use. The ruined remains of Kilspindie Castle are just to the south-east of the site. There are only a few blocks of masonary left to indicate the location of this 16th century castle. Aberlady Bay was Britain's first Local Nature Reserve to open in 1952. Concrete tank blockades are in situ to the west of the site, a remnant from past wars.
Aesthetic landscape	Coastal landscape
History of Earth Sciences	No known association
Economic geology	No known association

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

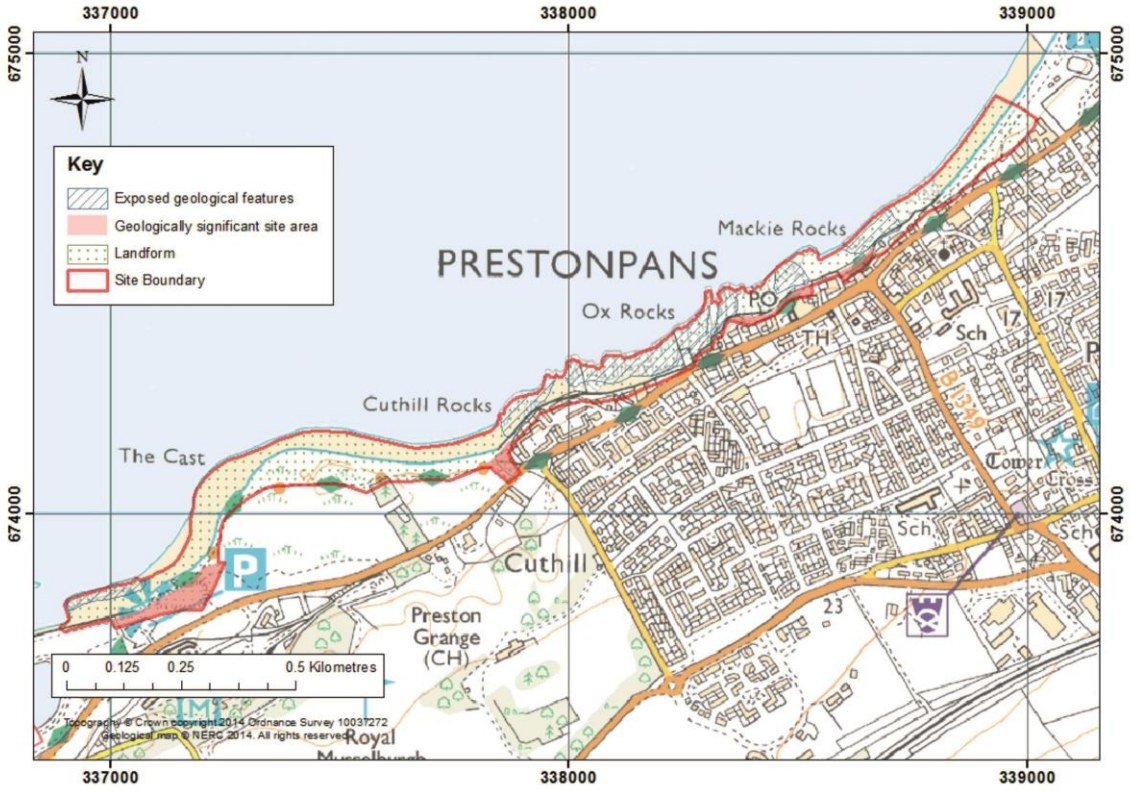


Figure 20: Prestonpans Shore Location Map. The site comprises areas of bedrock exposure (coastal rock platforms), and beaches. Bedrock exposure is likely to vary over time due to changes in beach morphology. Areas of the site important for access or viewing of features are included as geologically significant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

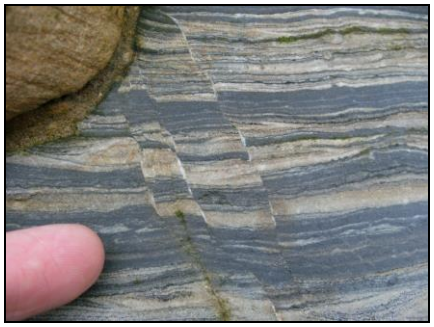


Photo ELC_15 P12: Faults with cm-scale, normal displacement are found throughout the site cross-cutting strata.. Some of the fault planes have been mineralised by calcite (white mineral), evidence that fault planes here acted as conduits to fluid flow. © BGS, NERC.

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

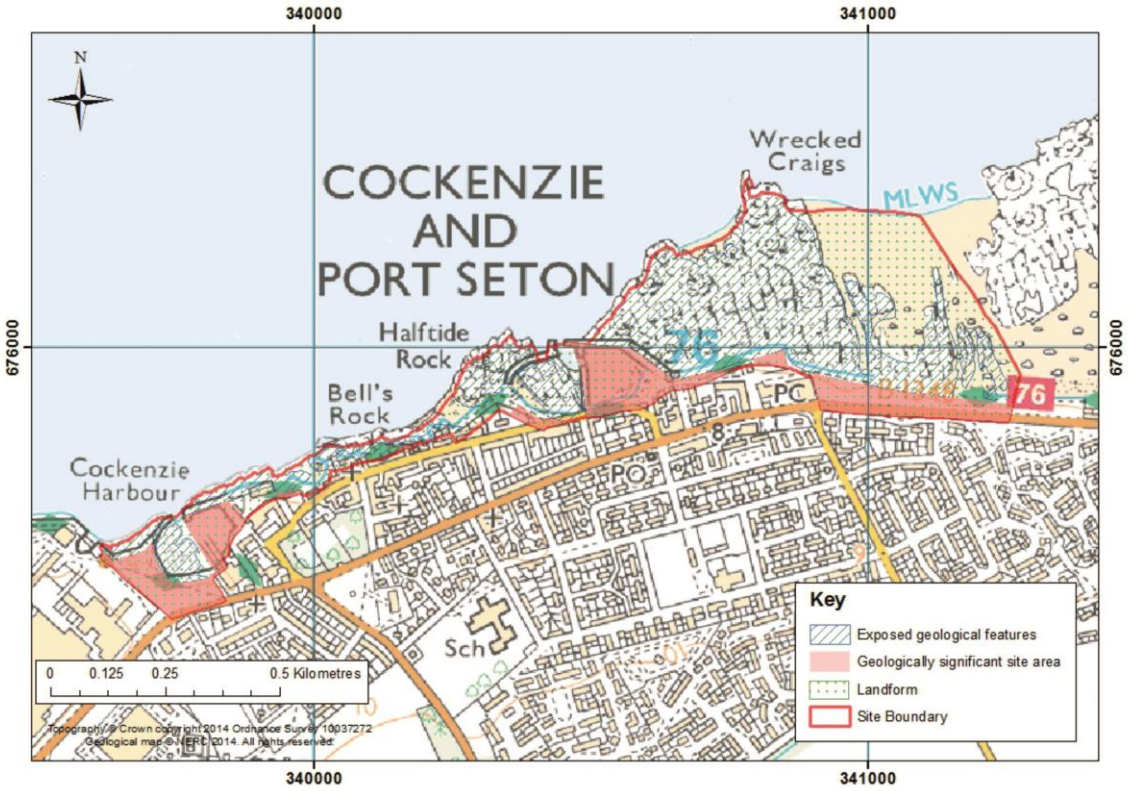


Figure 21: Cockenzie and Port Seton Location Map. The site comprises bedrock exposed in shore platforms and adjacent areas of beach. Bedrock exposures likely to vary over time due to changes in beach morphology. Areas of the site important for access or viewing of features are included as geologically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

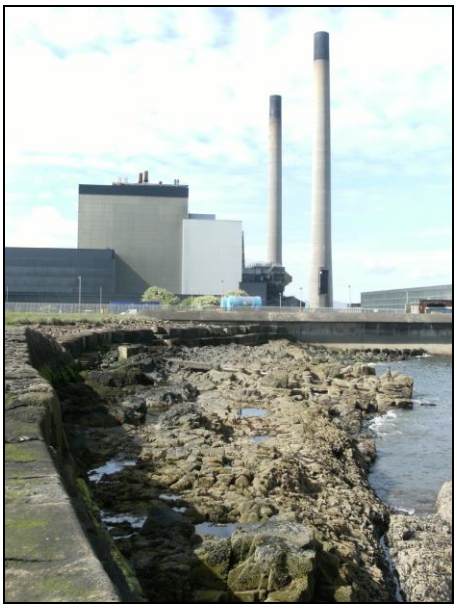


Photo ELC_16 P1: Cockenzie Power Station, looking west. The rocks in the foreground are the igneous rocks of the Port Seton-Spittal Dyke**.** © BGS, NERC.

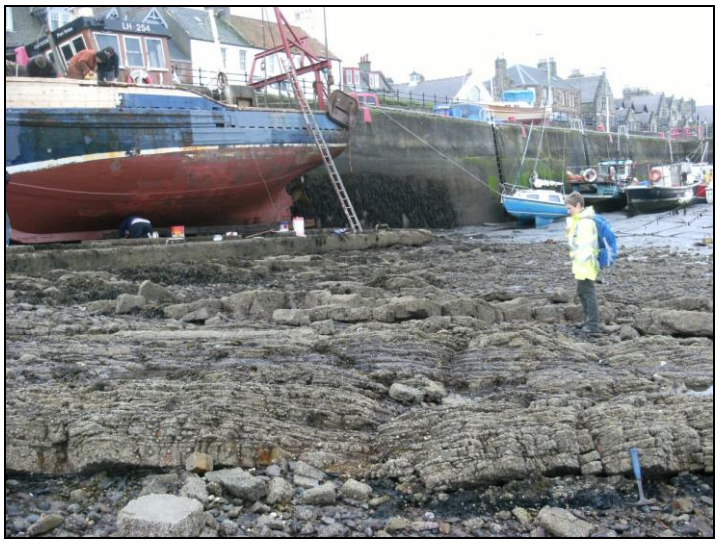


Photo ELC_16 P2: Port Seton Harbour; thinly bedded strata dipping south-west, of the Lower Coal Measures showing sandstones, mudstones and siltstones, a thin band of coal can be seen in the bottom right hand corner where the hammer is positioned. © BGS, NERC.

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

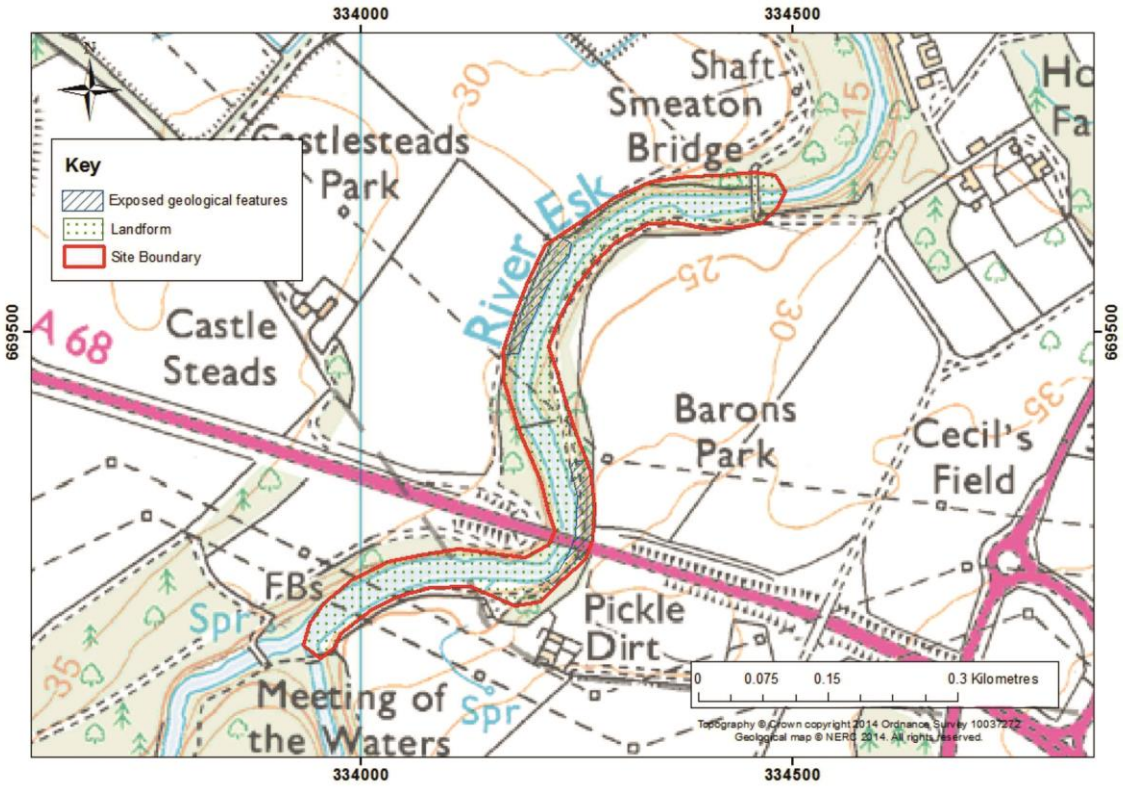


Figure 22: River Esk Location Map. The site comprises the incised gorge of the River Esk (landform) in which bedrock is exposed along the steep banks. The geologically significant area in the southern part of the site provides a good location for studying the cliff section.

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

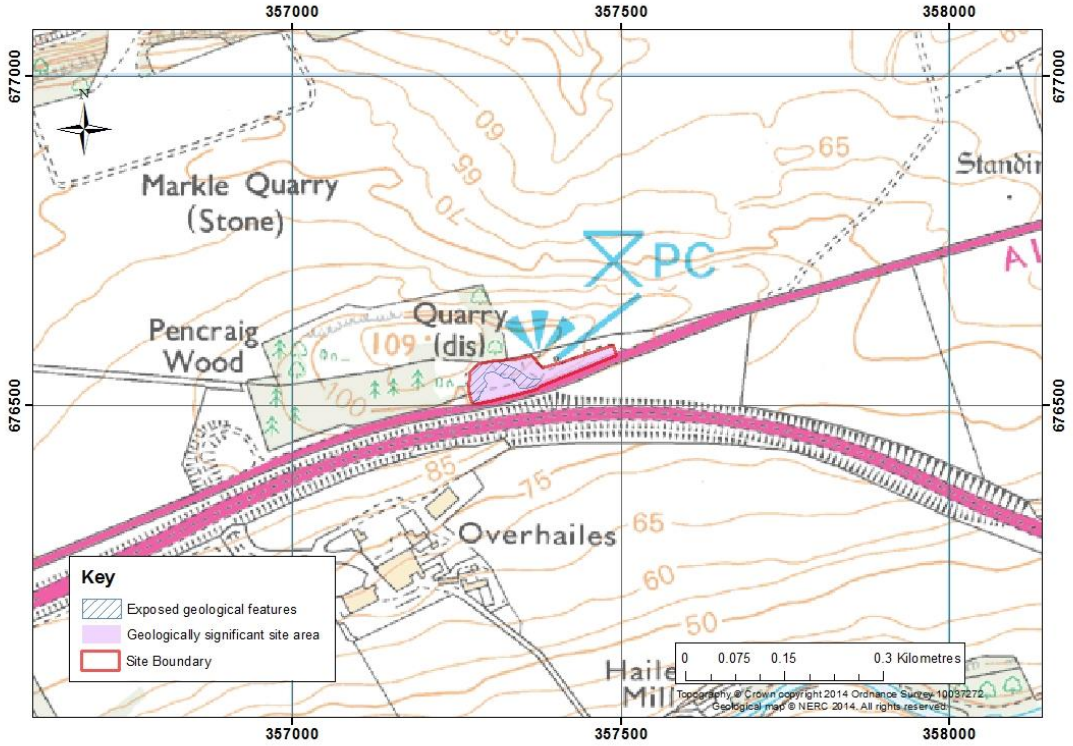


Figure 23: Pencraig Wood Location Map. Site boundary has been drawn to include rock exposures (blue hatched areas) and also site access and viewpoints (drawn as geologically significant site area).

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

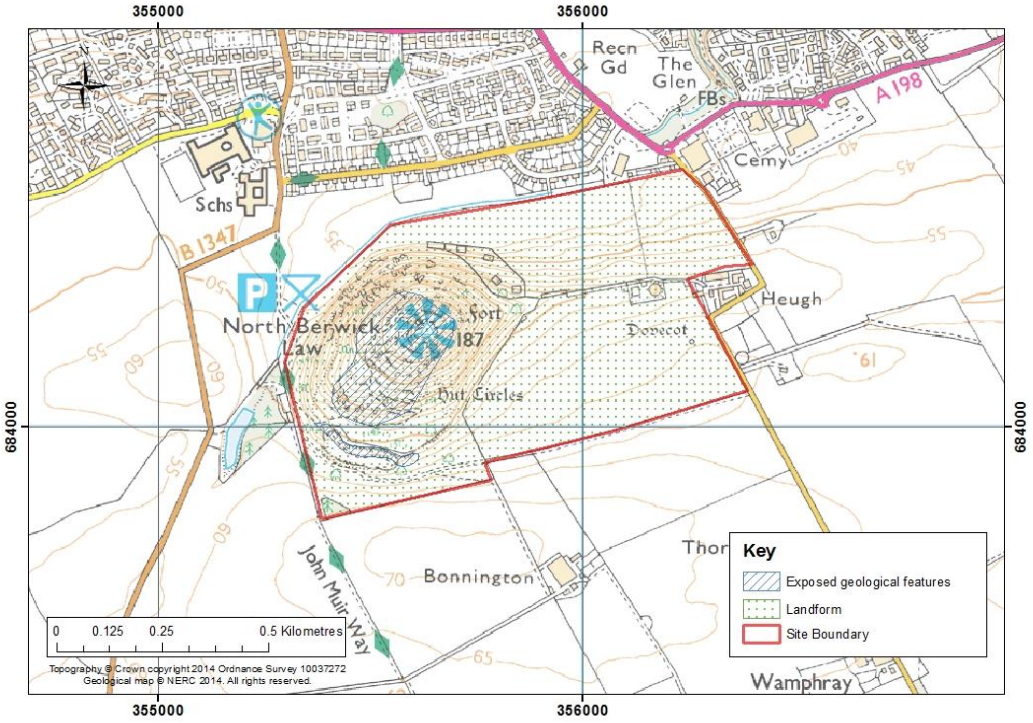


Figure 24: North Berwick Law Location Map. The site boundary includes the crag and tail feature of North Berwick Law and related bedrock exposures, only the proximal part of the landform 'tail' to the east is included. The site boundary coincides in part with that of the lowland calcareous grassland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

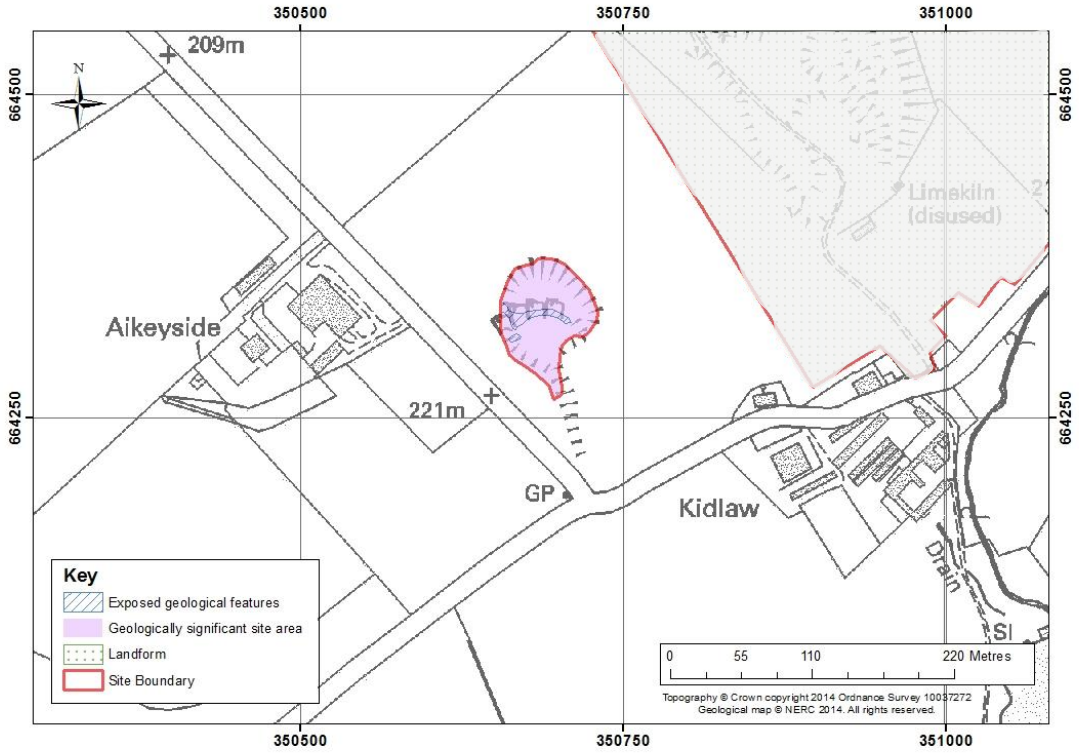


Figure 25: Kidlaw Quarry Location Map. The site boundary has been drawn to include the rock exposures within the quarry, and related access and viewpoints (geologically significant site areas). The site boundary for the Kidlaw Erratic (ELC_22) to the east is included for reference (shaded area).

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

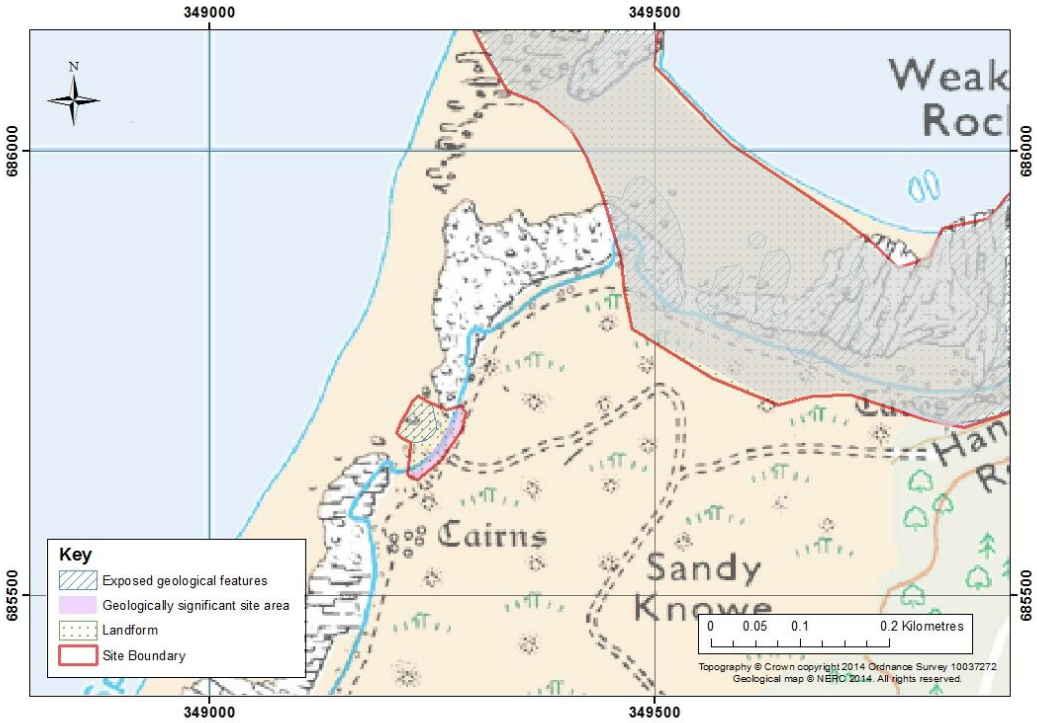


Figure 26: Cheese Bay Location Map. The site boundary has been drawn to include the bedrock exposure containing the Shrimp Bed for which Cheese Bay is known. The adjacent intertidal zone and is also included due to its potential for containing fossiliferous mudstone pebbles, derived from the Shrimp Bed.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

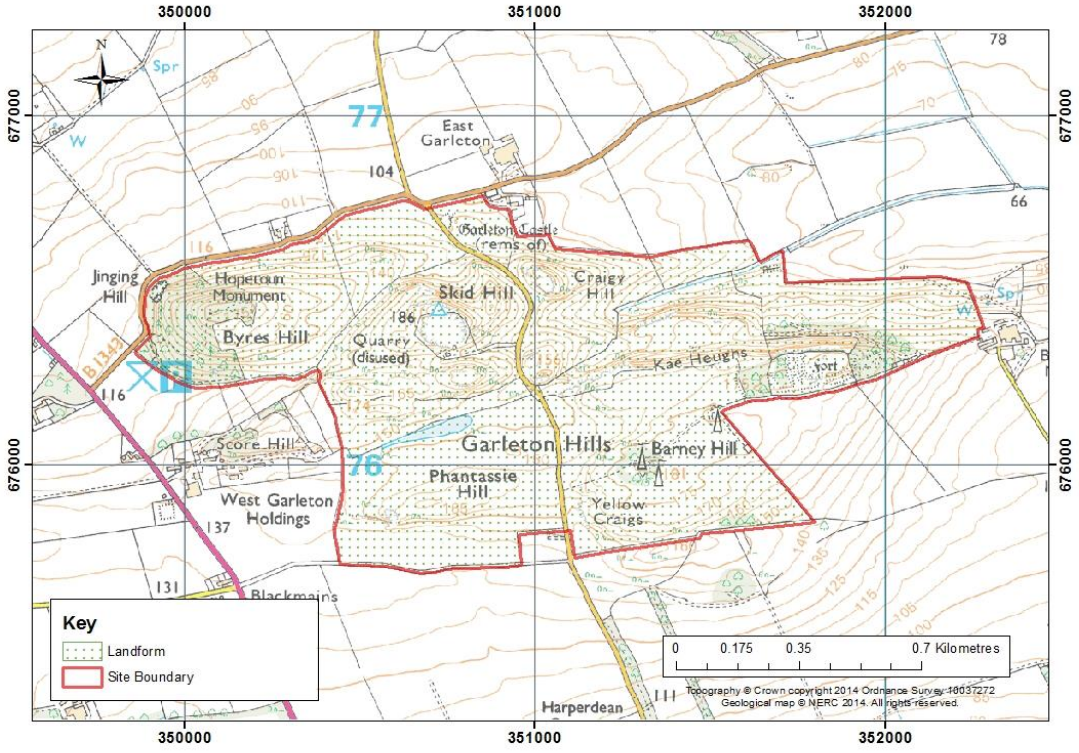


Figure 27: Garleton Hills Location Map. The site boundary covers an area of erosional glacial landforms. The area contains numerous exposures of volcanic bedrock, but these have not been marked as they are already covered by SSSI designation.

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

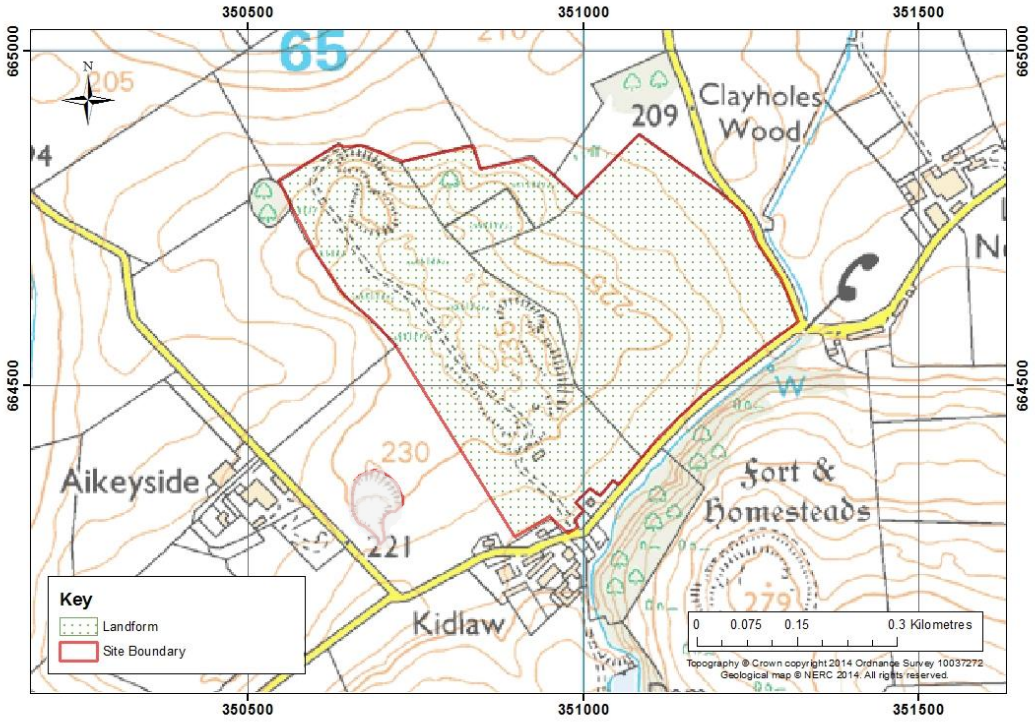


Figure 28: Kidlaw Erratic Location Map. The site boundary is drawn to include the main upstanding mass of limestone and its continuation below the adjacent moundy lower ground to the east as marked on the BGS 1:50k solid geology Sheet 33W. The site boundary for the Kidlaw Quarry (ELC_20) to the west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

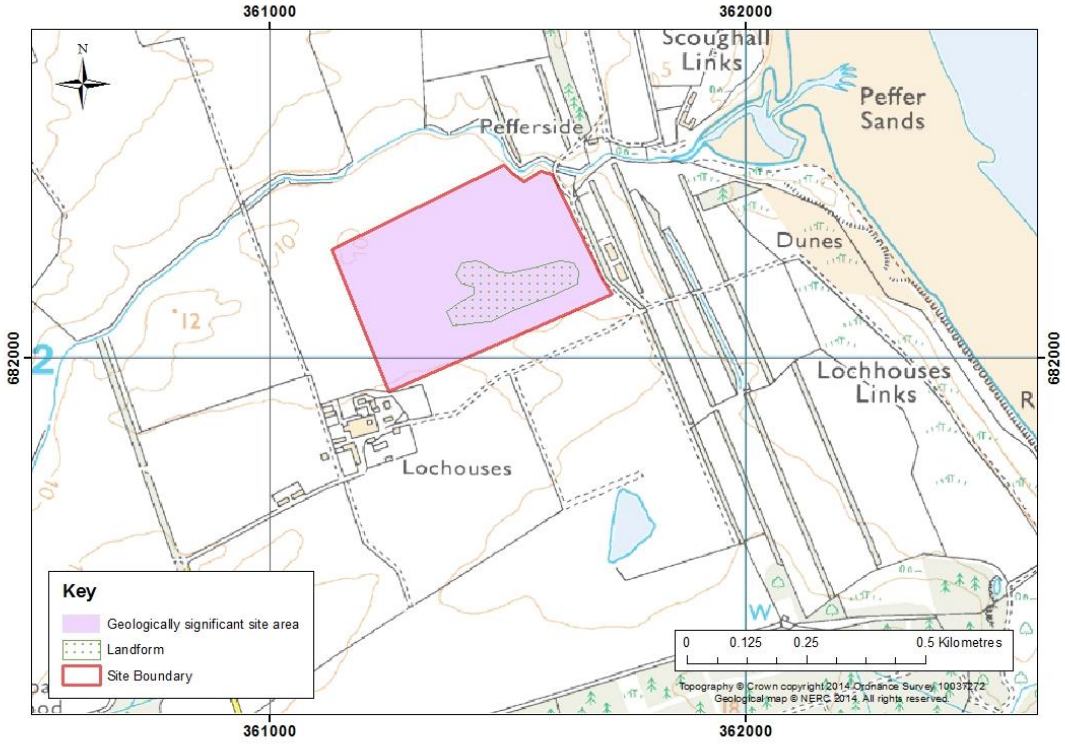


Figure 29: Lochhouses Location Map. Suggested site boundary includes the field boundary surrounding the landform in which the tsunami deposits are found.

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

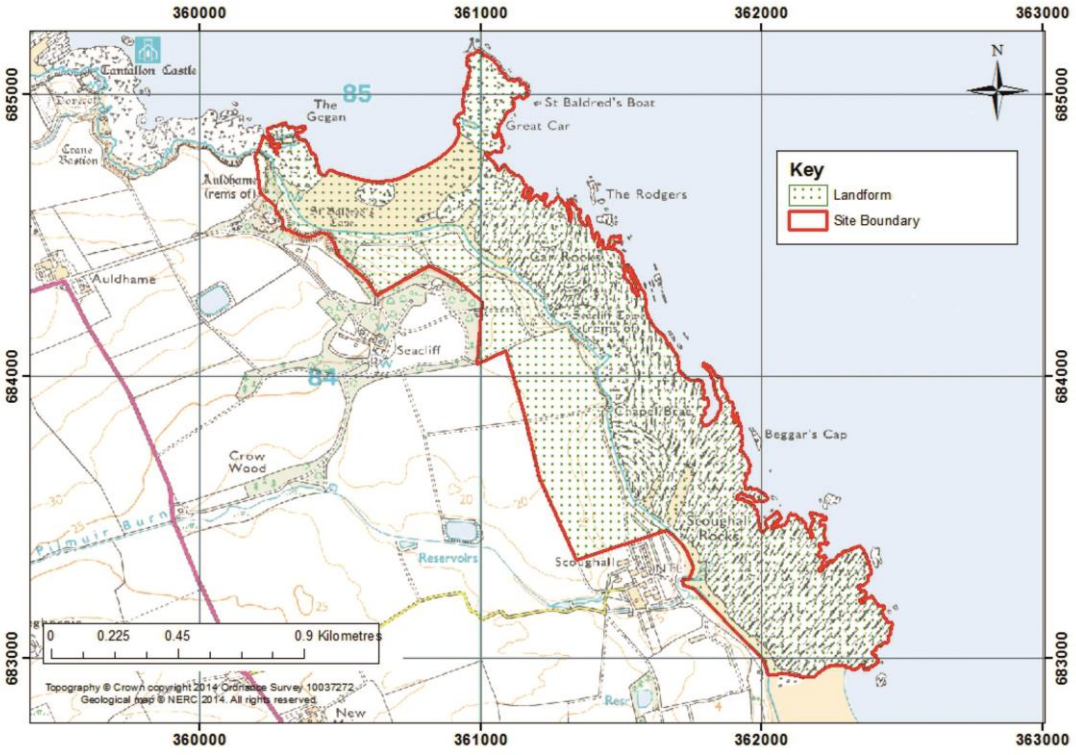


Figure 30: Seacliff-Scoughall Shore Location Map. The site boundary covers the landforms comprising shore platforms, backing cliffs, and postglacial raised beaches.

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.

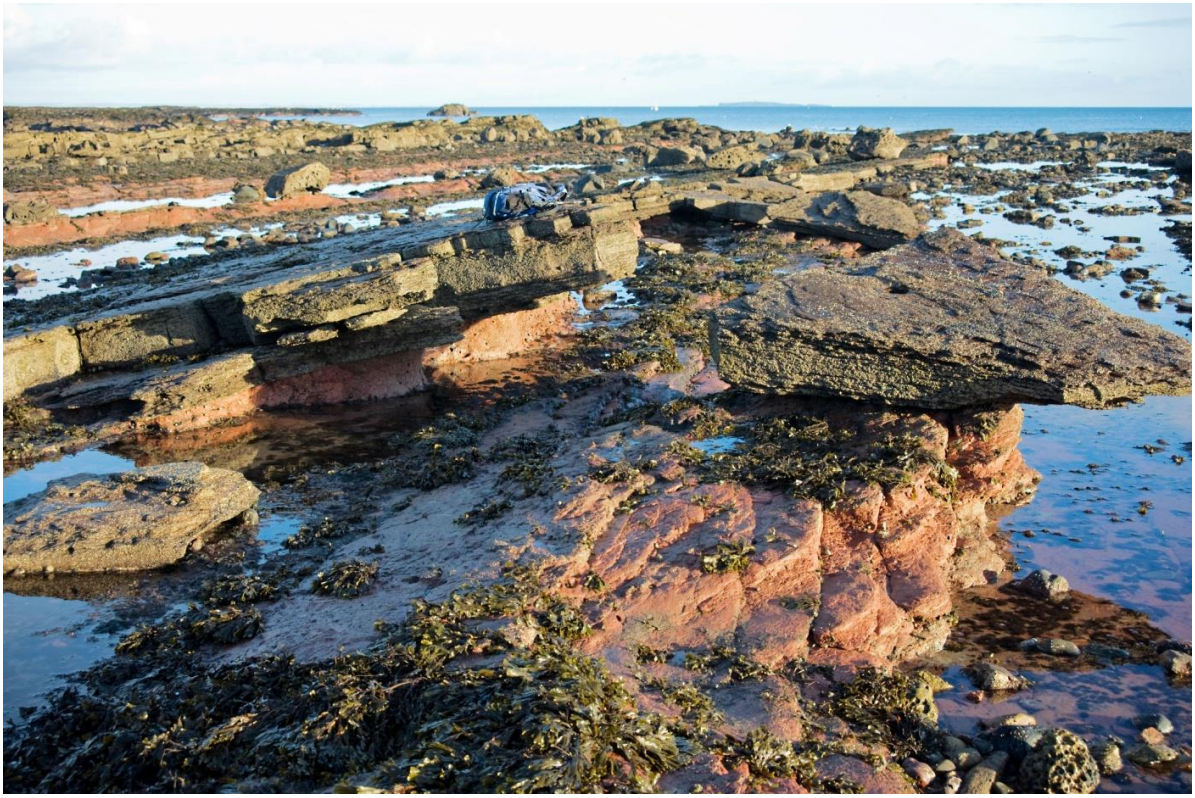


Photo ELC_25 P5: Undercut collapsed blocks on the shore platform south of Great Scar © John Gordon.

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

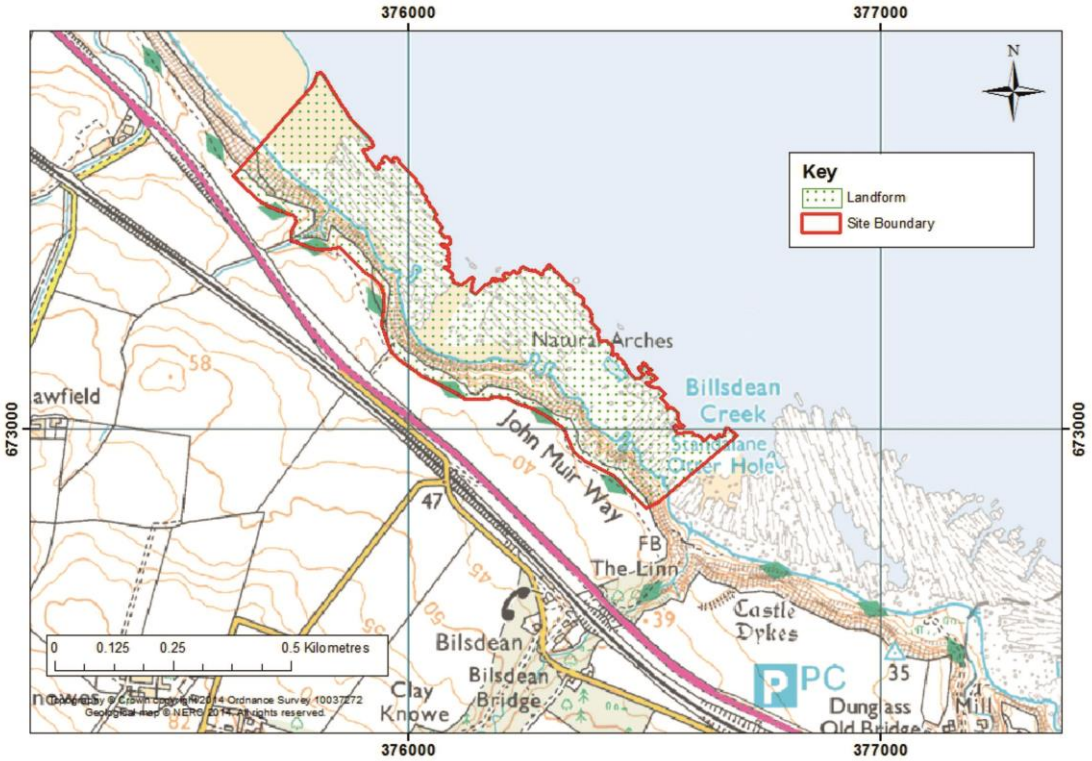


Figure 31: Thorntonloch Coast Location Map. The site boundary has been drawn to include the rock cliffs and intertidal shore platform.

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.

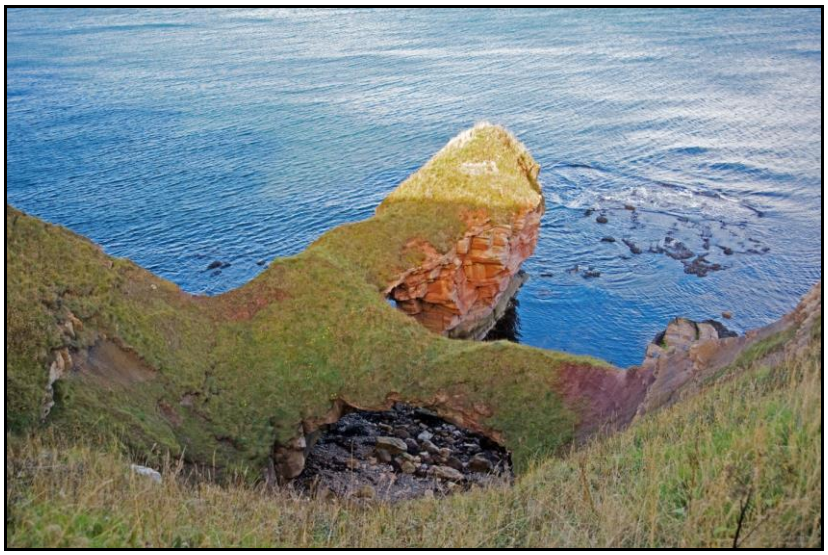


Photo ELC_26 P3: Former partly collapsed blowhole and arch, southern headland. Photo looking north. © John Gordon.

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.

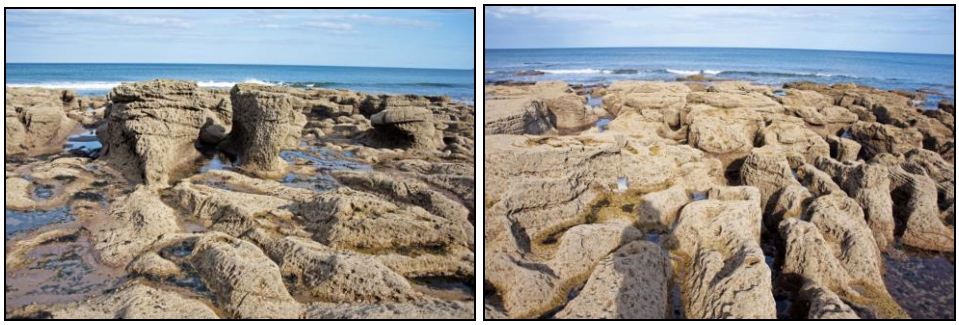


Photo ELC_26 P6: Runnels and solutional weathering near the seaward edge of the intertidal rock platform**.** © John Gordon.

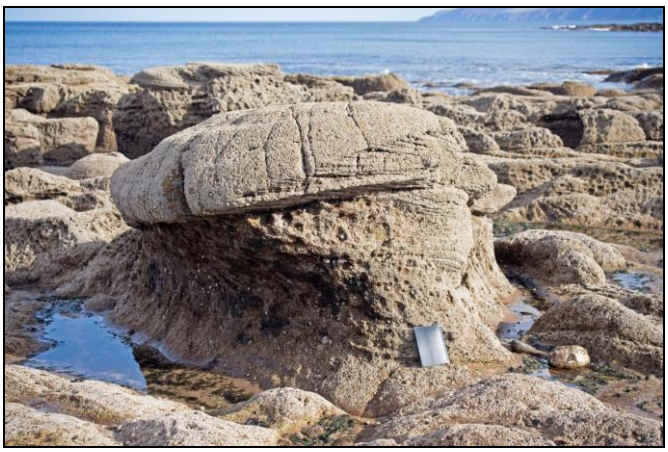


Photo ELC_26 P7: Differential weathering under a 'caprock' calcretion in the sandstone**.** © John Gordon.

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

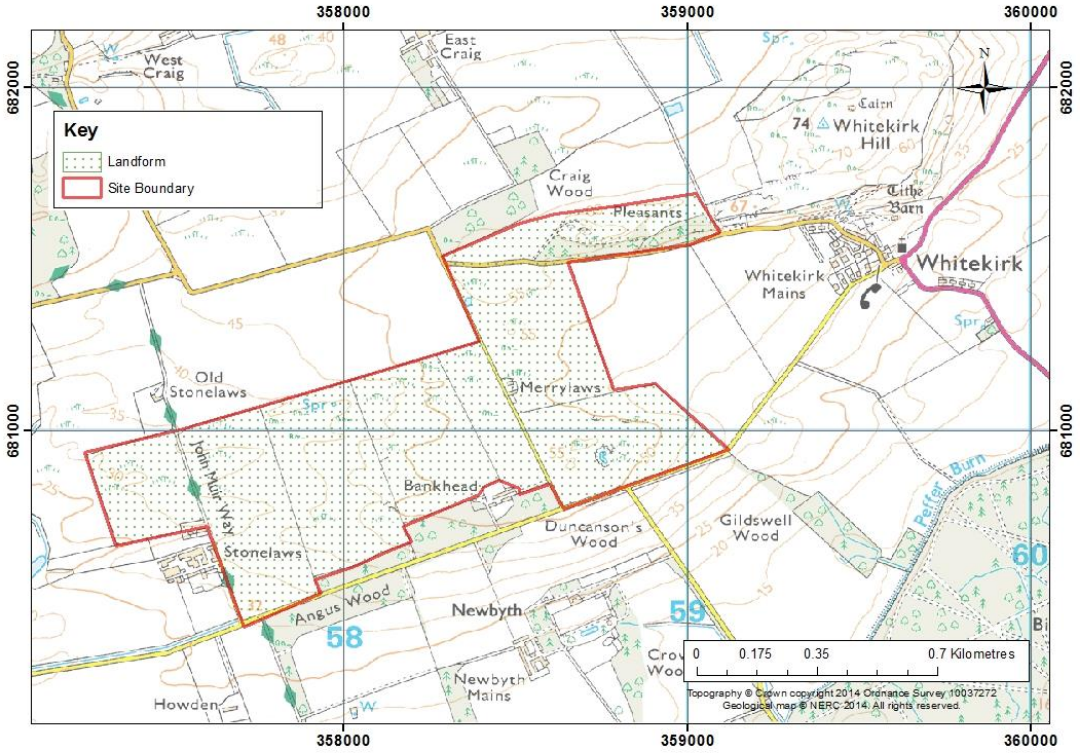


Figure 32: Whitekirk Location Map. The site boundary is drawn to include a representative area of ice-moulded bedrock.

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

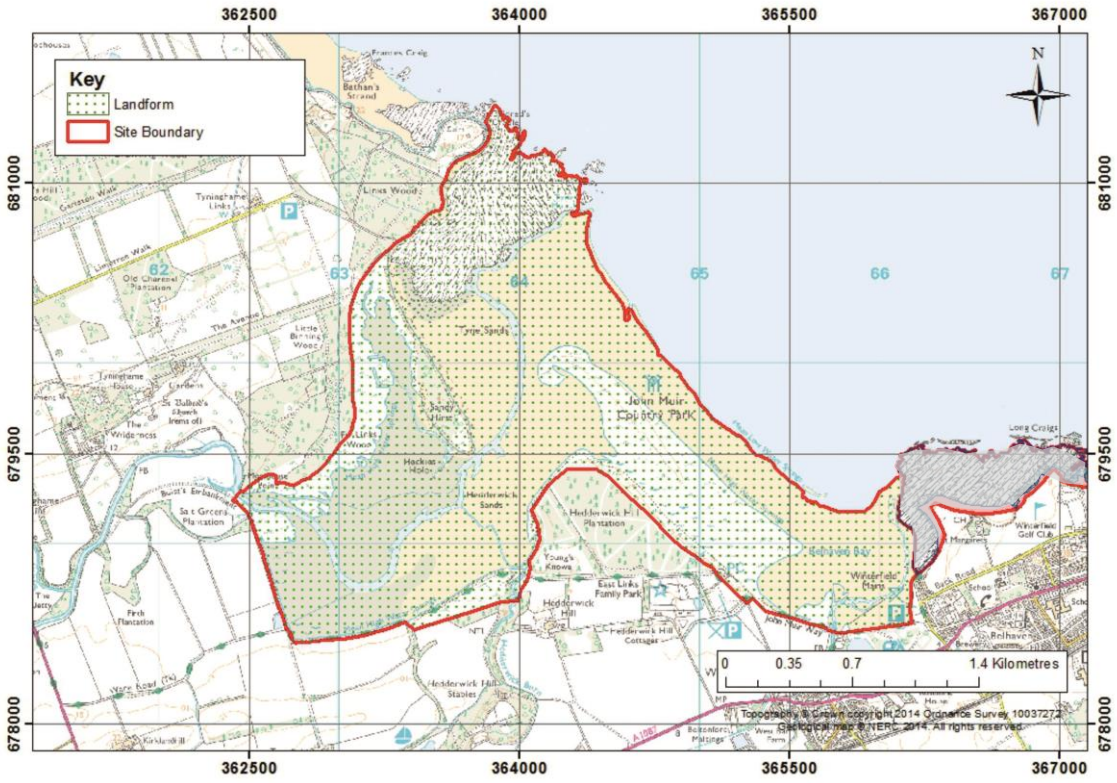


Figure 33: Tyne Estuary Map. The site boundary includes the landform assemblage of the modern estuary and bay as an integral coastal geomorphology unit. The adjacent bedrock and Quaternary site at Dunbar (ELC_4) is shown for reference (transparent grey area).

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

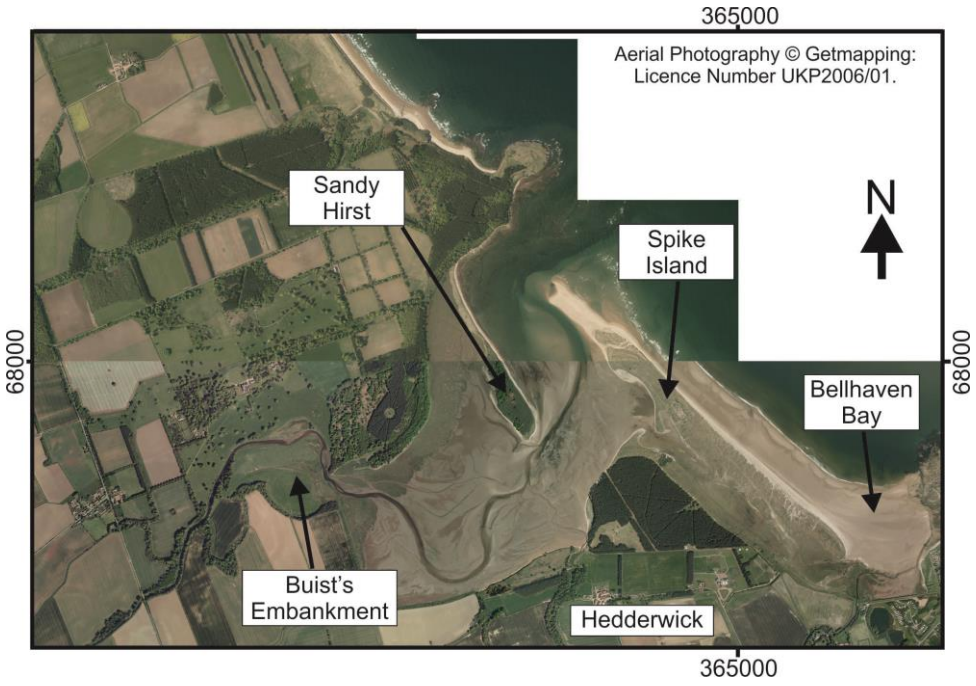


Photo ELC_28 P1: Satellite image showing the diversity of geomorphological features present.

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

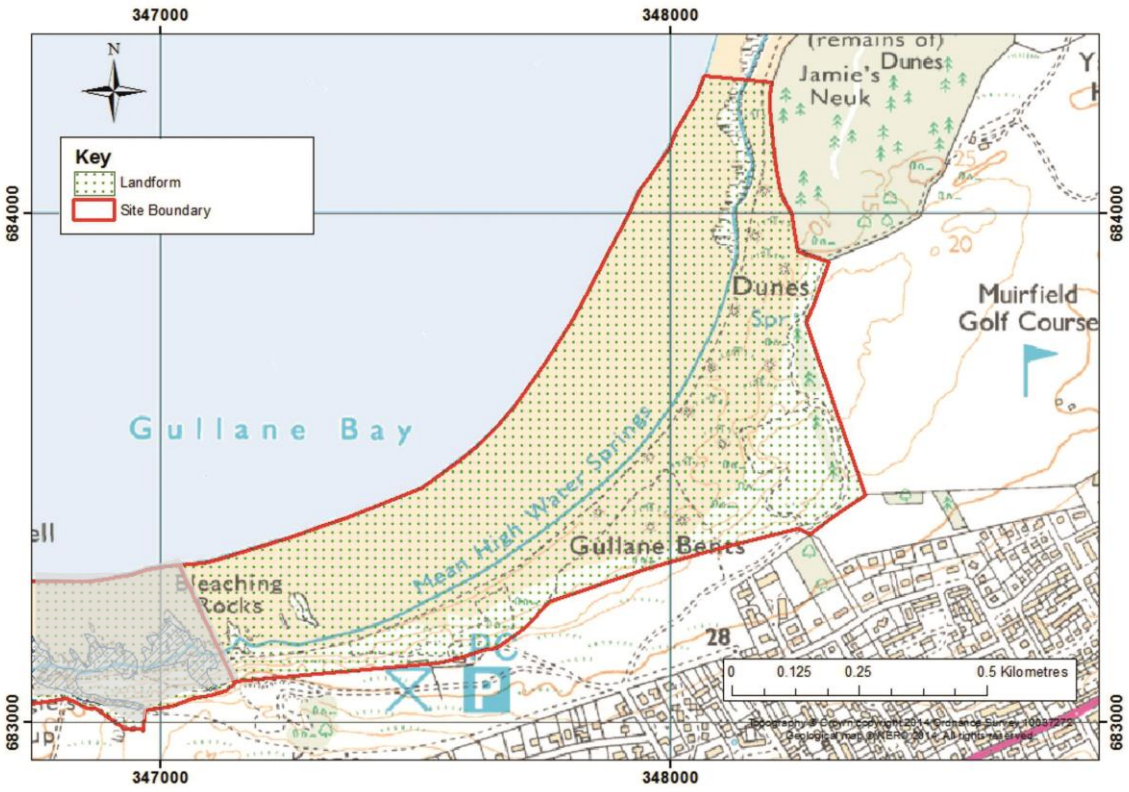


Figure 34: Gullane Bents Map. The site boundary includes the sand flats of Gullane Bay, the Gullane Bents dune system and backing cliff. The site boundary for the adjacent Gullane Shore bedrock/Quaternary site (ELC_13) to the west is included (ELC_30) (transparent grey polygon). It should be noted that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

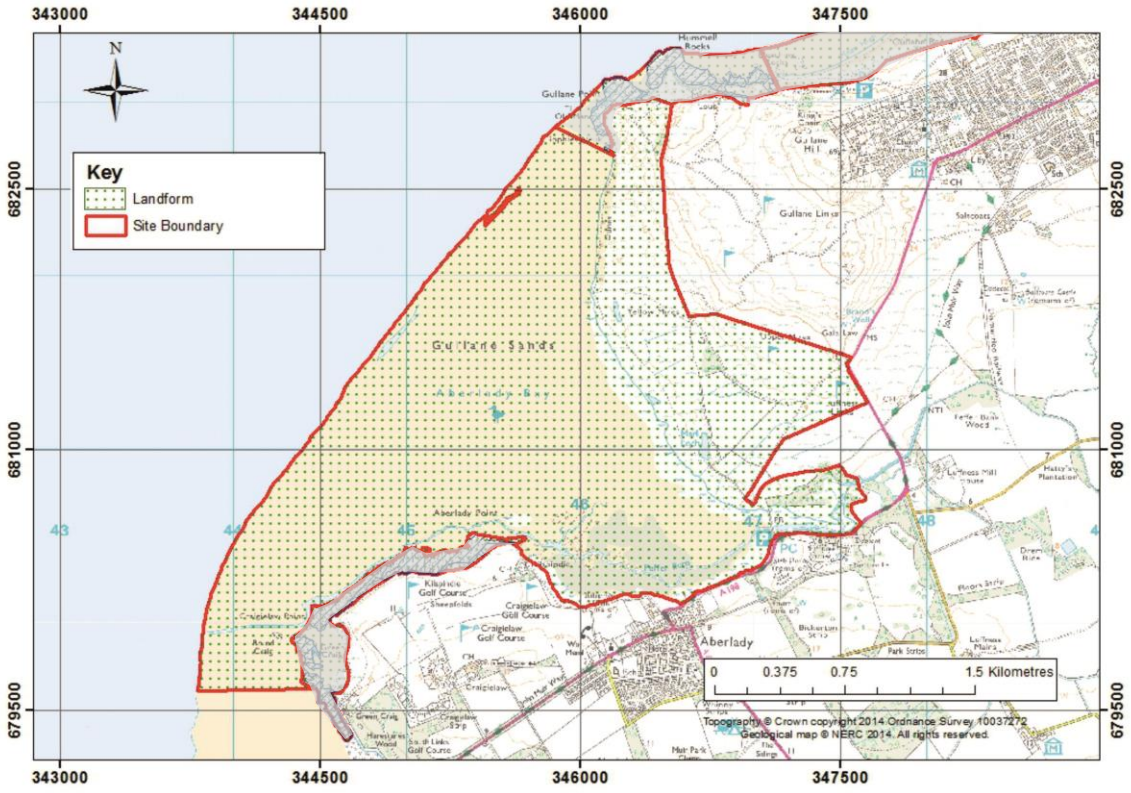


Figure 35: Aberlady Bay Map. The site boundary has been drawn to include the dominant intertidal portion of Aberlady Bay including sand flats, and the dune system. The site boundary is largely coincident with that of the Aberlady Bay Local Nature Reserve. The neighbouring bedrock/Quaternary ELC Geodiversity 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)

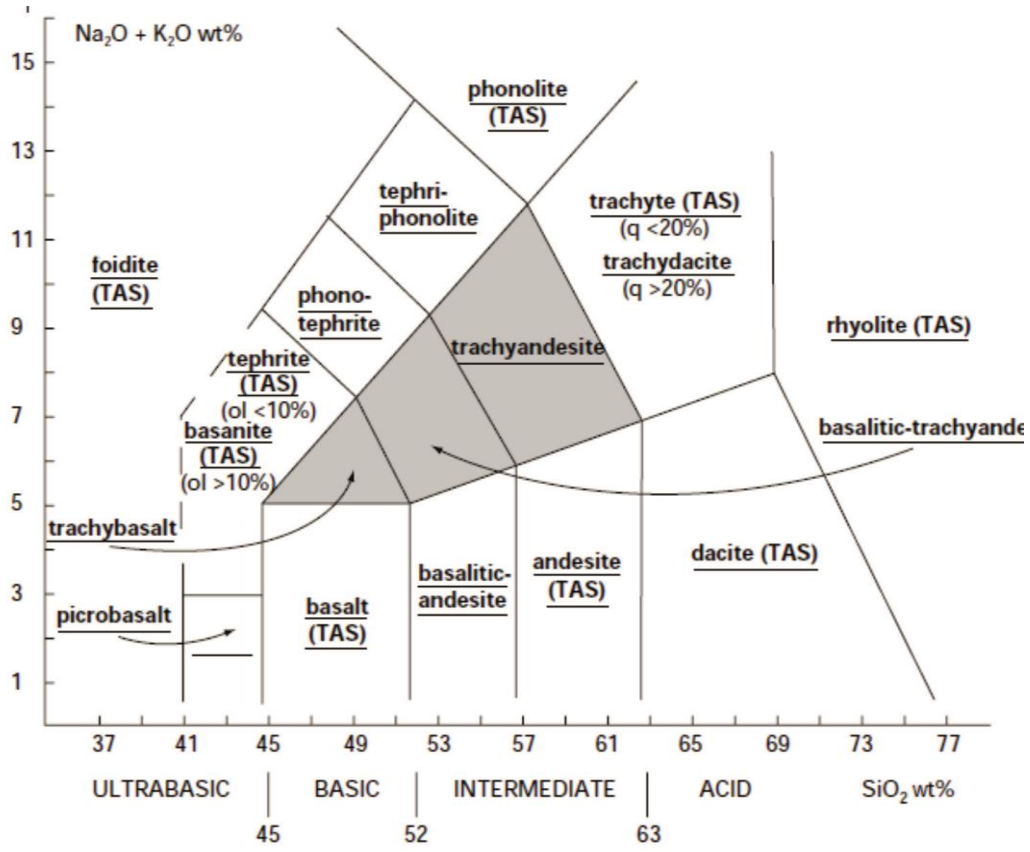
Table 10: Sites already designated as a 'Local Geodiversity Site' and/or have existing geological leaflets.

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.

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.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

BABTIE GROUP ABP RESEARCH & CONSULTANCY LTD. 2002. East Lothian Council Shoreline Management Plan. Final Report. Babtie Group, Glasgow.

BRIGGS, D E G and Clarkson, E N K. 1983. The Lower Carboniferous Granton 'shrimp bed', Edinburgh. In *Trilobites and other early arthropods: papers in honour of Professor H. B.Whittington, F.R.S. (eds. D.E.G. Briggs and P.D. Lane), Special Papers in Palaeontology*, **30**, 616–77.

BROWNE, M A E, DEAN, M T, HALL, I H S, MCADAM, A D, MONRO, S K and CHISLOM, J I. 1999. A lithostratigraphical framework for the Carboniferous rocks of the Midland Valley of Scotland. British Geological Survey Research Report, RR/99/07. 67pp.

BROWNE, M A E, SMITH, R A and AITKEN, A M. 2002. Stratigraphical framework for the Devonian (Old Red Sandstone) rocks of Scotland south of a line from Fort William to Aberdeen. British Geological Survey Research Report, RR/01/04. 67pp.

CRAIG, G Y and DUFF, P M D. 1975. (Editors) *The Geology of the Lothians and south east Scotland. (Edinburgh:* Edinburgh Geological Society, Scottish Academic Press).

CLOUGH, C T, BARROW G, CRAMPTON C B, MAUFE H B, BAILEY E B and ANDERSON, E M. 1910. The Geology of East Lothian (second edition). *Memoir of the British Geological Survey*, Explanation of Sheet 33, with parts of 34 & 41 (Scotland).

DAVIES, A, MCADAM, A D AND CAMERON, I B. 1986. Geology of the Dunbar district. *Memoir of the Geological Survey, 1:50 000 Sheet 33E and part of Sheet 41 (Scotland)*.

DAY, T C and BAILEY, E B. 1987. Bombs of nepheline-basanite in the Partan Craig Vent, North Berwick, *Transactions of the Edinburgh Geological Society, v.12 p87-89.*

DAY, T C. 1928. The volcanic vents on the shore between North Berwick and Tantallon Castle. *Trans. Edinburgh Geol. Sot.,* Vol. 12, 41-52.

DINELEY, D and METCALF, S. 1999. *Fossil Fishes of Great Britain*, Geological Conservation Review Series, No. 16, Joint Nature Conservation Committee, Peterborough. ISBN 1 86107 470 0

EWING, C M. 1913. A Geographical Description of East Lothian, *Scottish Geographical Magazine, p 23.*

FIRTH, C R, COLLINS, P E F and SMITH, D E. 1997. Coastal processes and management of Scottish estuaries. IV - the Firth of Forth. *Scottish Natural Heritage Review*, No. 87.

GORDON, J E, AND SUTHERLAND, D G. 1993. Quaternary of Scotland. Geological Conservation Review Series, No. 6, Chapman and Hall, London, 695 pp.

HAFLIDASON, H., SEJRUP, H P, NYGÅRD, A, MIENERT, J, BRYN, P, LIEN, R, FORSBERG, C F, BERG, K and MASSON, D. 2004. The Storegga Slide: architecture, geometry and slide development. *Marine Geology*, 313, 201-234.

HALL, A.M. 2011. Storm wave currents, boulder movement and shore platform development: A case study from East Lothian, Scotland. *Marine Geology*, 283, 98-105.

HALL, A. 2012. East Lothian Landscapes [online: http://www.landforms.eu/Lothian/]

JACKES, M. 1973. Sites of geomorphological interest in East Lothian. Unpublished report to the Nature Conservancy Council, Edinburgh.

KENDALL, P F and BAILEY, E B. 1908. The glaciation of East Lothian south of the Garleton Hills. *Transactions of the Royal Society of Edinburgh*, 46, 1-31.

KIRBY, R P. 1997. Aberlady Bay coastal landforms and coastal vegetation communities. *Scottish Geographical Magazine*, 113, 121-126

MAY, V J AND HANSOM, J D. 2003. Coastal Geomorphology of Great Britain, Geological Conservation Review Series, No. 28, Joint Nature Conservation Committee, Peterborough, 754 pp.

MCADAM, A D and TULLOCH, W. 1985. Geology of the Haddington district. *Memoir of the Geological Survey, 1:50 000 Sheet 33W (Scotland)*.

MCADAM, A D and CLARKSON, E N K. 1986. *Lothian geology: An excursion guide. (Edinburgh:* Edinburgh Geological Society, Scottish Academic Press).

MITCHELL, G H and MYKURA, W. 1962. The Geology of the Neighbourhood of Edinburgh (third edition). *Memoir of the British Geological Survey*, Explanation of Sheet 32 (Scotland).

NEWEY, W W. 1965. Post-glacial vegetational and climatic changes in part of south-east Scotland. Unpublished PhD thesis, University of Edinburgh.

PATTON, R L SMITHSON, T R and CLACK, J A. 1999. An amniote-like skeleton from the Early Carboniferous of Scotland. Nature, 398, 508-513.

PEACOCK, J D. 1999. The pre-Windermere Interstadial (Late Devensian) raised marine strata of eastern Scotland and their macrofauna: a review. *Quaternary Science Reviews*, 18, 1655-1680.

ROBERTSON, T, SIMPSON, J B and ANDERSON, J G C. 1949. The Limestones of Scotland. *Memoir of the Geological Survey of Great Britain.*

ROBINSON, M. 1982. Diatom analysis of early Flandrian lagoon sediments from East Lothian, Scotland. *Journal of Biogeography*, 9, 207-222.

ROSE, N. 1980. Beaches of Southeast Scotland. Department of Geography, University of Aberdeen, for the Countryside Commission for Scotland. Reprinted 2001 by Scottish National Heritage as a Commissioned Report. [Available online]

SHI, S. 1995. Observational and theoretical aspects of tsunami sedimentation. Unpublished PhD thesis, Coventry University.

SIMPSON, J. 1928. Notes on the geology of the Kidlaw District, East Lothian. *The Geology of East Lothian, Transactions of the Edinburgh Geological Society, 12, 111-113.*

SISSONS, J B. 1958. The deglaciation of parts of East Lothian. *Transactions of the Institute of British Geographers*, 25, 59 – 77.

SISSONS, J B. 1975. The geomorphology of East Lothian. In Craig, G. Y. and Duff, P. McL. D. (eds), *The Geology of the Lothians and South-east Scotland: an Excursion Guide*. Scottish Academic Press, Edinburgh, 131-143.

SMITH, D E, SHI, S., CULLINGFORD, R A, DAWSON, A G, DAWSON, S, FIRTH, C R, FOSTER, I D L, FRETWELL, P T, HAGGART, B A, HOLLOWAY, L K and LONG, D. 2004. The Holocene Storegga Slide tsunami in the United Kingdom. *Quaternary Science Reviews*, 23, 2291-2321.

SMITH, D E, HUNT, N, FIRTH, C R, JORDAN, J T, FRETWELL, P T, HARMAN, M, MURDY, J, ORFORD, J D and BURNSIDE, N G. 2012. Patterns of Holocene relative sea level change in the North of Britain and Ireland. *Quaternary Science Reviews*, 52, 58-76.

SMITH, S M. 1972. Palaeoecology of post-glacial beaches in East Lothian. *Scottish Journal of Geology*, 8, 31-49.

SMITH, W W, 1959. Pseudomorphs after olivine in Markle basalt. Mineralogical Magazine, v.32, 247, p. 324-331.

STACE, H and LARWOOD, J G. 2006. Natural Foundations: geodiversity for people, places and nature. (Peterborough: English Nature.)

STONE, P., MCMILLAN, A.A., FLOYD, J.D., BARNES, R.P AND PHILLIPS, E.R. 2012. British Regional Geology: South of Scotland (Fourth Edition). (Keyworth, Nottingham: British Geological Survey).

TRAQUAIR, R H. 1904. *Summary of Progress of the Geological Survey of Great Britain for 1903*. HMSO, London, pp. 121–3.

TRAQUAIR, R H. 1907. Report on fossil fishes collected by the Geological Survey of Scotland from shales exposed on the shore near Gullane, East Lothian. *Transactions of the Royal Society, Edinburgh*, **41**, 103–17.

TULLOCH, W and WALTON, H S. 1958. The Geology of the Mid Lothian Coalfield. *Memoir of the Geological Survey of Great Britain.*

WERRITTY, A and MCEWEN, L J. 1997. Oldhamstocks Burn. In: Gregory, K.J. (ed.), *Fluvial Geomorphology of Great Britain*. Geological Conservation Review Series No. 13. Joint Nature Conservation Committee, Peterborough, 97-99.