Members' Library Service Request Form

Date of Document	30/08/16
Originator	Douglas Proudfoot
Originator's Ref (if any)	
Document Title	Proposed Local Development Plan Technical Note 11: Planning for Geodiversity

Please indicate if access to the document is to be "unrestricted" or "restricted", with regard to the terms of the Local Government (Access to Information) Act 1985.

Unrestricted	☒	Restricted	☐

If the document is "restricted", please state on what grounds (click on grey area for drop-down menu):

For Publication

Please indicate which committee this document should be recorded into (click on grey area for drop-down menu):

East Lothian Council

Additional information:

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

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

For Office Use Only:	
Library Reference	140/16
Date Received	30/08/16
Bulletin	Aug 16

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 2016. East Lothian Geodiversity Audit. *British Geological Survey Open Report*, OR/14/063. 192pp.

Edinburgh, Scotland British Geological Survey 2016

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. In January 2016, an extension of this work was commissioned by East Lothian Council to extend the audit to include the Forth Islands. The Forth Islands site assessment is included at the end of this report in Appendix 4.

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. In January 2016, an extension of the audit was commissioned by East Lothian Council to include the Forth Islands. The Forth Islands site assessment is included at the end of this report in Appendix 4.

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.

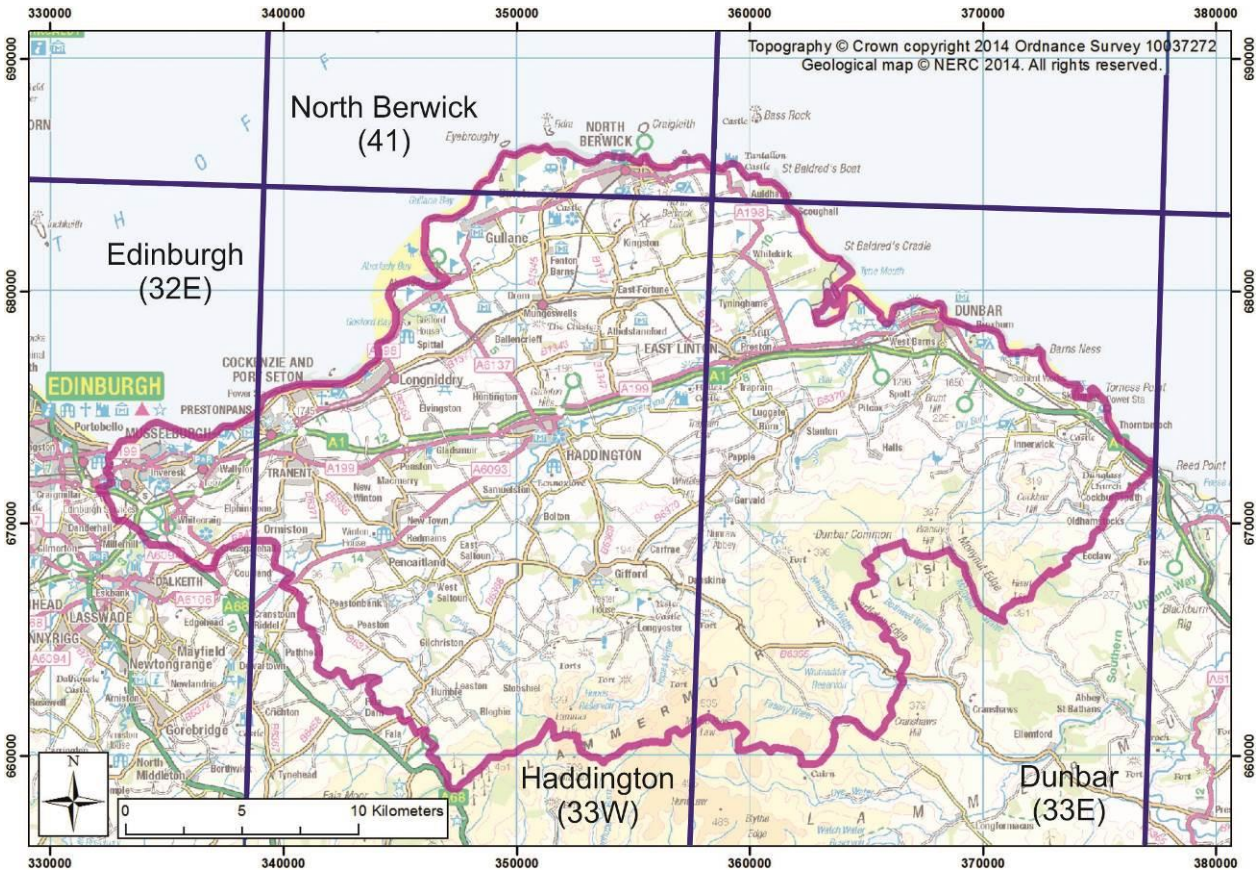


Figure 1 Location of East Lothian Council area (pink outline) and the distribution of 1: 50 000 scale BGS geological map sheets (blue lines).

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).

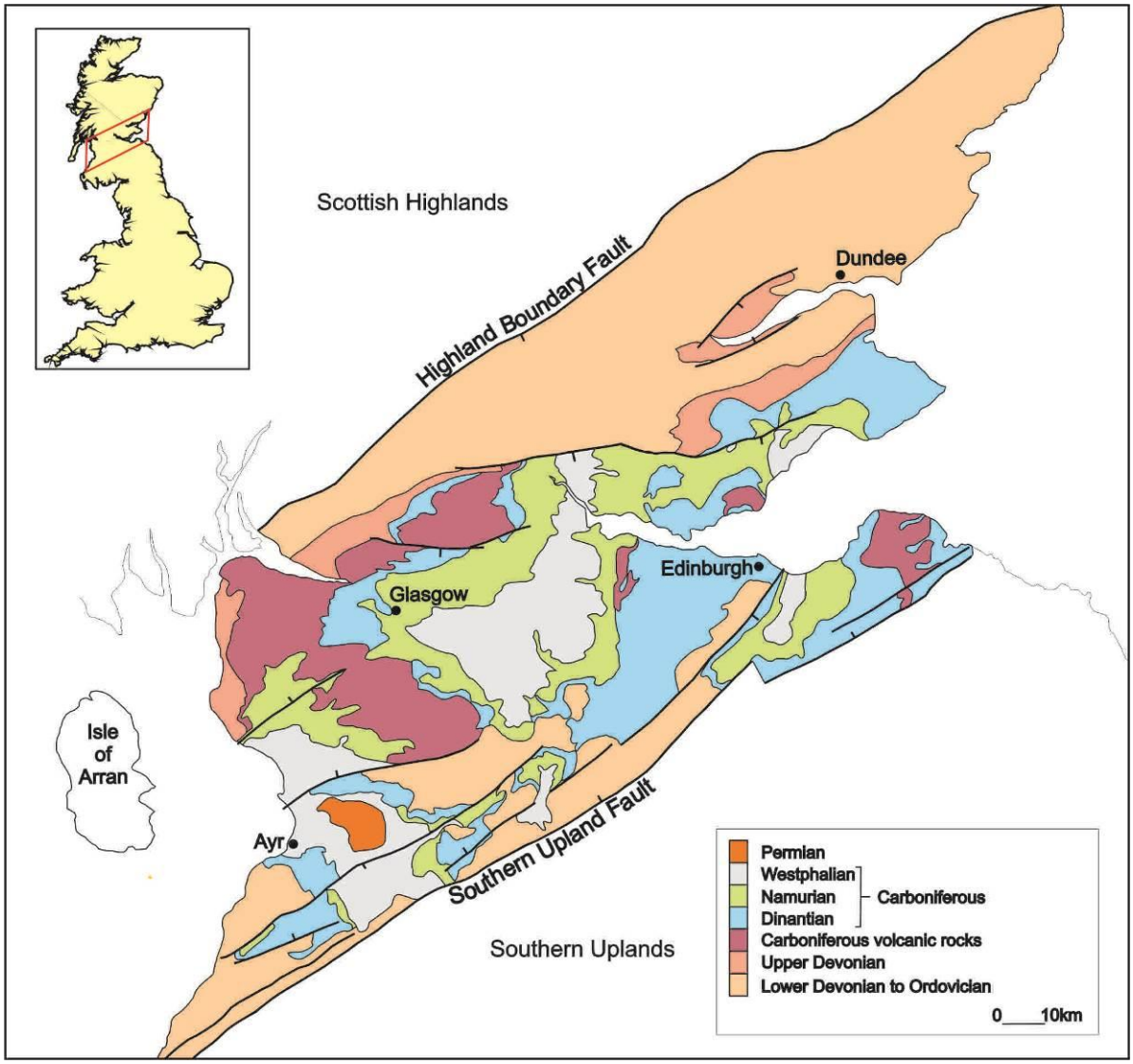
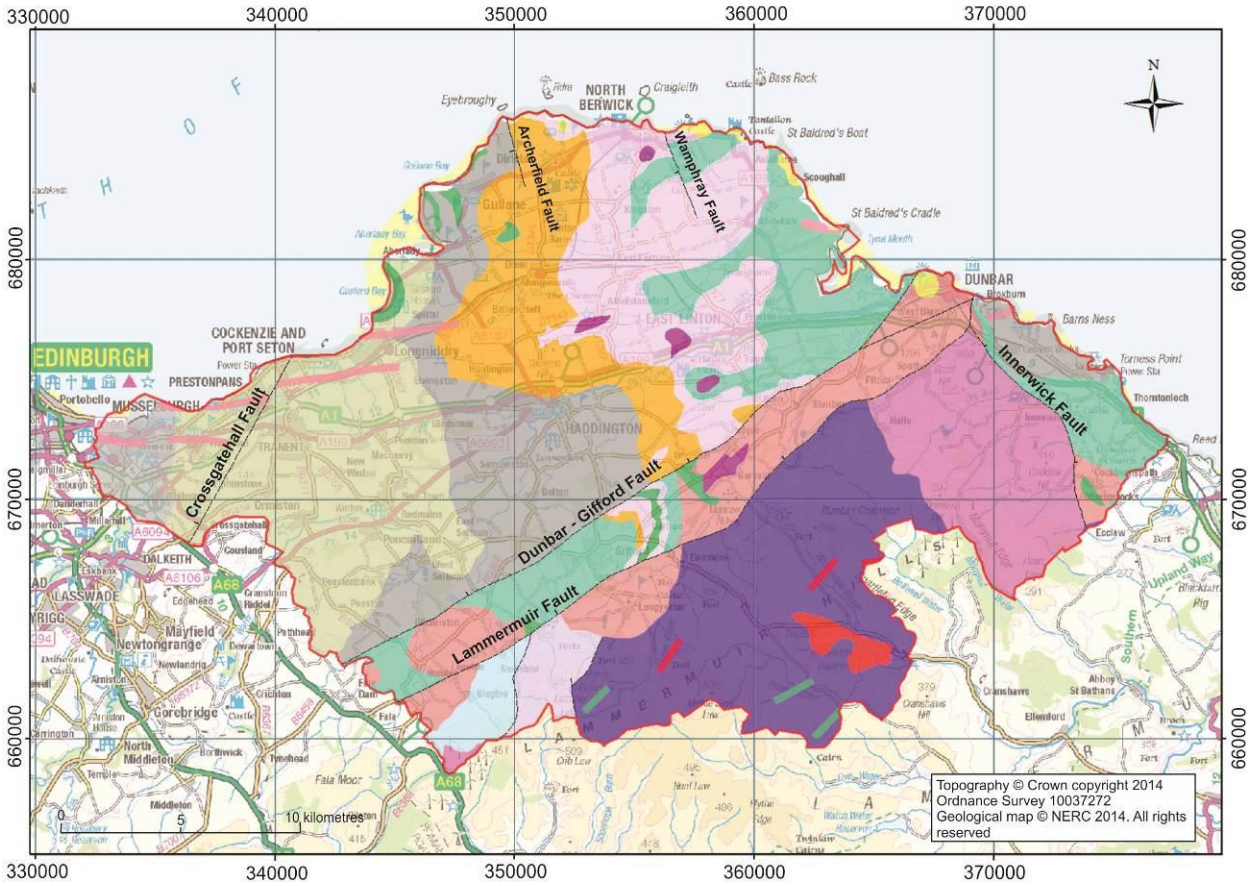


Figure 2 Simplified geological map of the Midland Valley of Scotland. Geological faults are shown by a thick black line with a tick on the downthrown side (Source: BGS DiGMapGB data).



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.

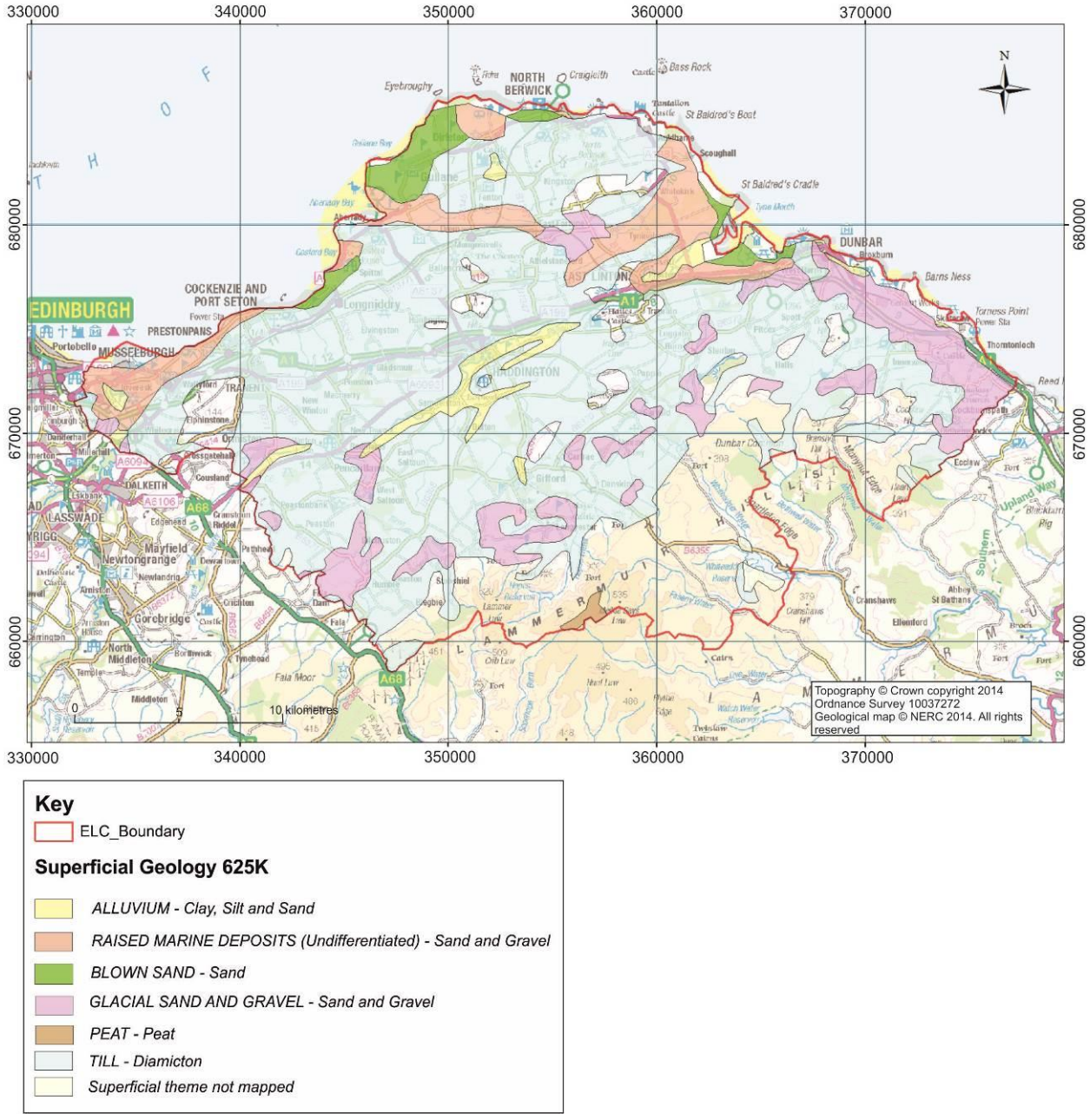


Figure 4 Superficial deposits of East Lothian

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.

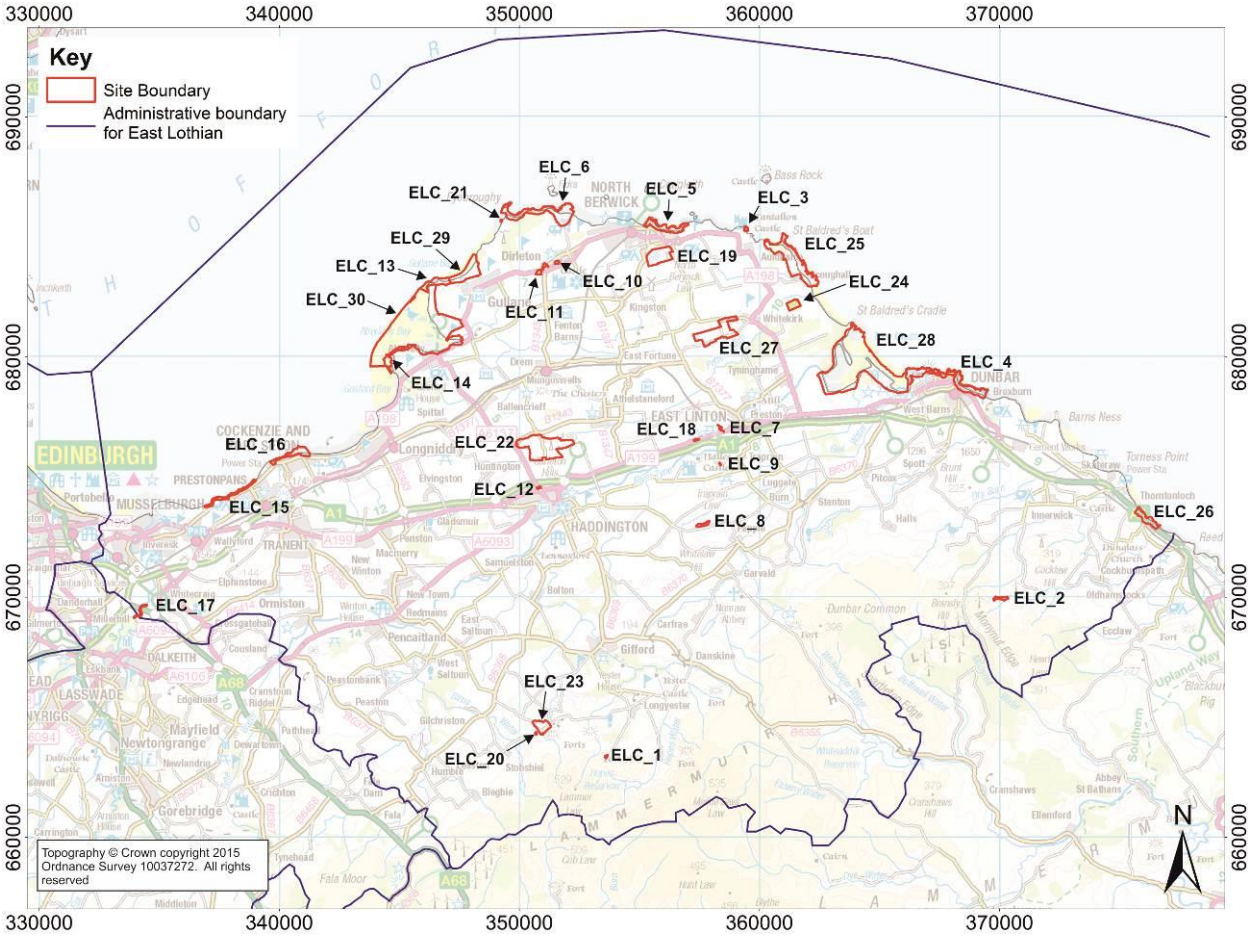


Figure 5 Location map of East Lothian Geodiversity Sites

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

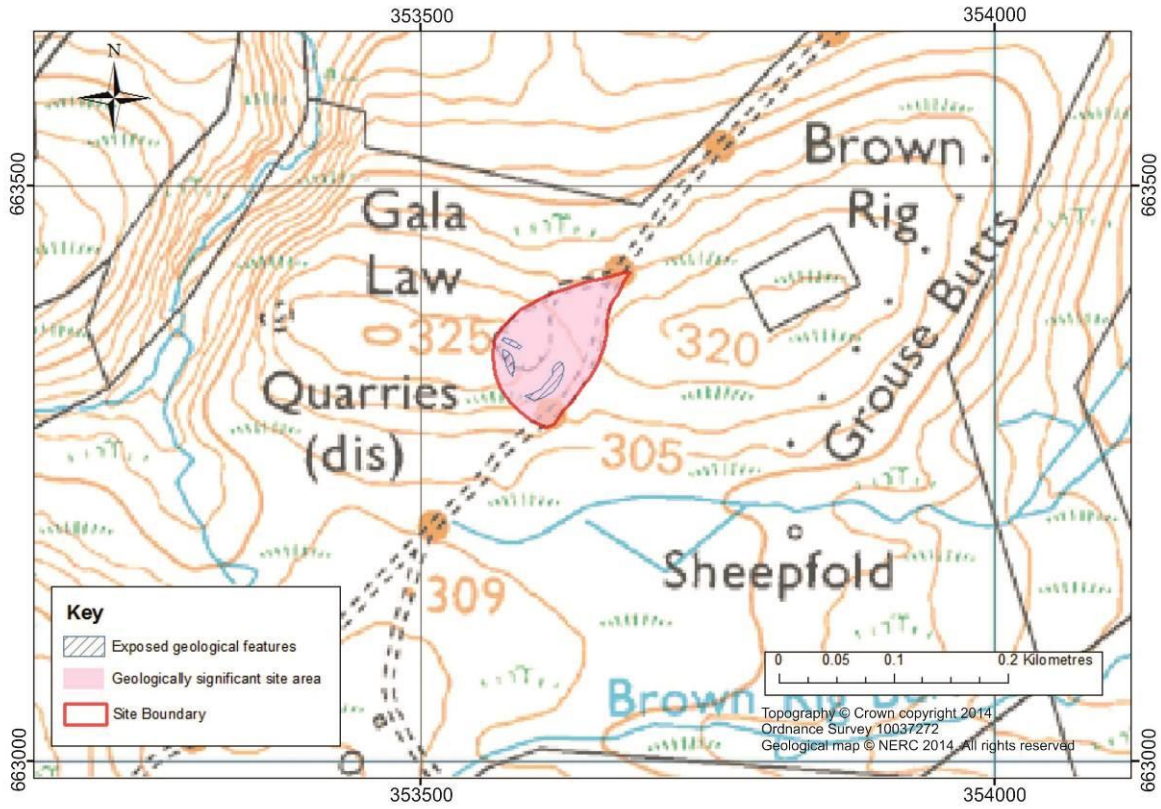


Figure 6: Gala Law Location Map. The site boundary includes key rock exposures, immediate access to the quarry, and viewpoints looking down into the quarry.

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

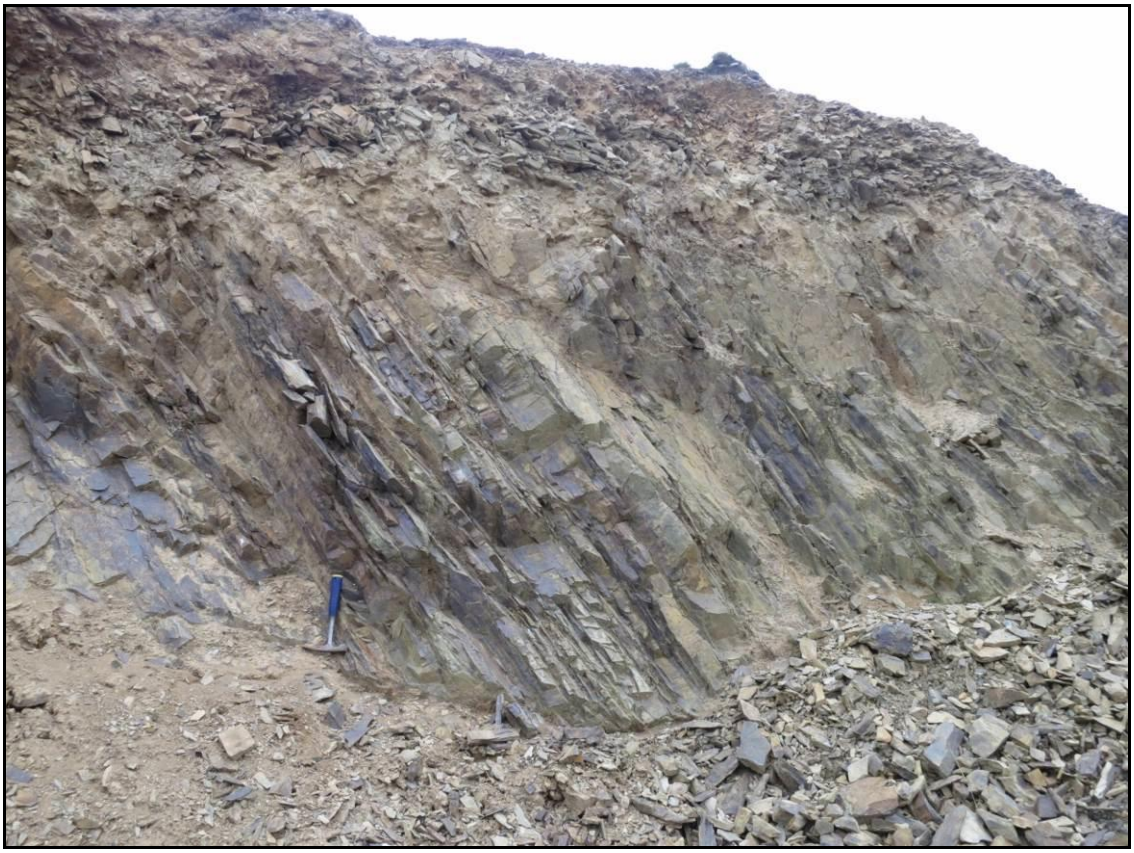


Photo ELC_1 P1: Steeply dipping, thinly bedded siltstones, mudstones and shales exposed in the east wall of the quarry at Gala Law. The thicker units are grey-brown siltstone, with thinner black shale and pale grey micaceous mudstone between. These sequences represent low-density submarine turbidity 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

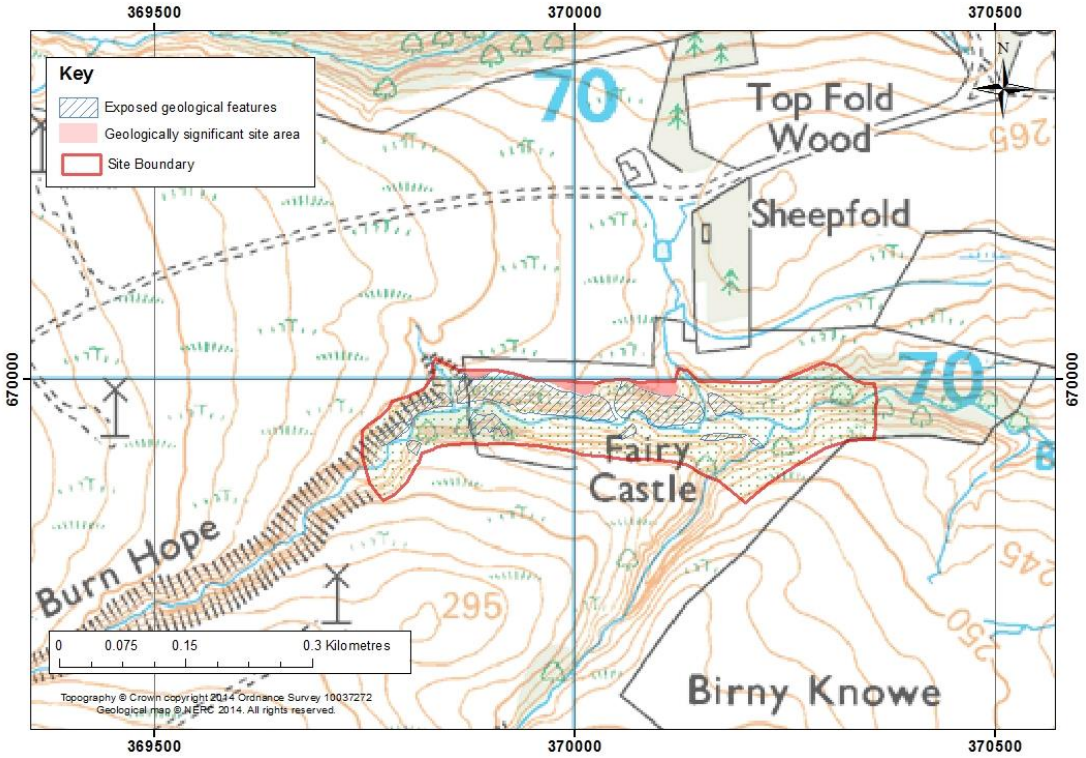


Figure 7: Burn Hope ('Fairy Glen') Location Map. The exact area of bedrock exposure is likely to vary over time due to erosion and changes in vegetation. The landform area covers the glacial meltwater channel along which the bedrock at the site is exposed, and is therefore included within the Site Boundary. 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

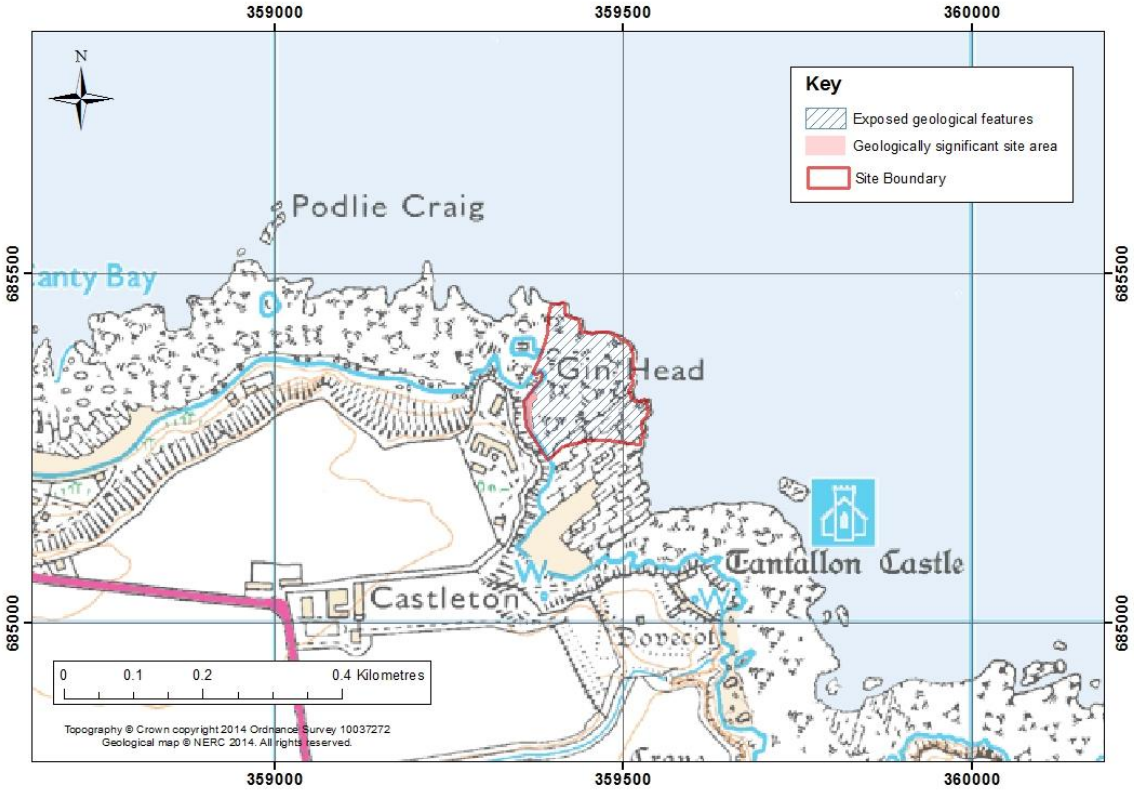


Figure 8: Gin Head (near Tantallon Castle) Location Map. The site boundary has been drawn to include all of the Ballagan Formation bedrock exposure at Gin Head, as well as the intertidal beach at the west of the site. The beach is mapped here as a geologically significant site area, as boulders containing 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

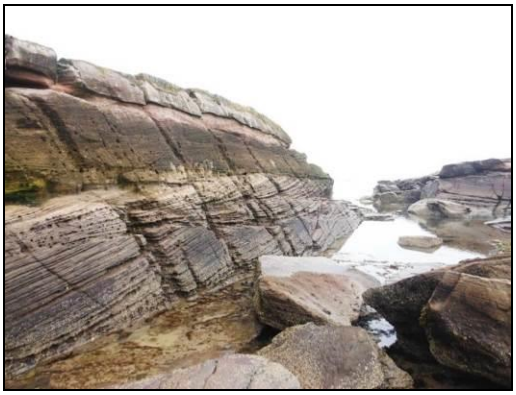


Photo ELC_3 P1: Trough cross-bedding developed within fluvial sandstones of the Ballagan Formation. Note the sub-horizontal bedding in the foreground is truncated by the cross-bedded layer, suggesting the cross-bedding developed within a river channel that actively eroded earlier deposits. Photo looking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

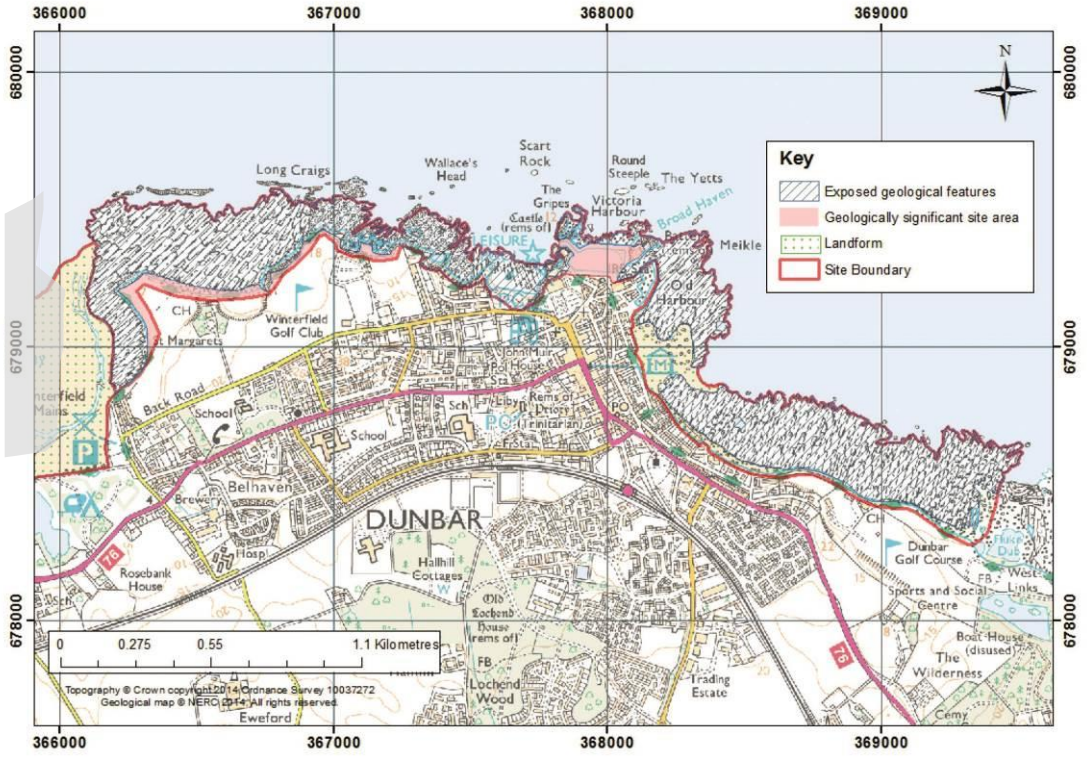


Figure 9: Dunbar Shore Location Map. The site comprises rock exposures along the shore platform and coastal landforms including shore platforms, raised beach, and areas of beach in the immediate vicinity of the main rock outcrops**,** The exact area of bedrock exposure (blue hatched areas) is likely 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

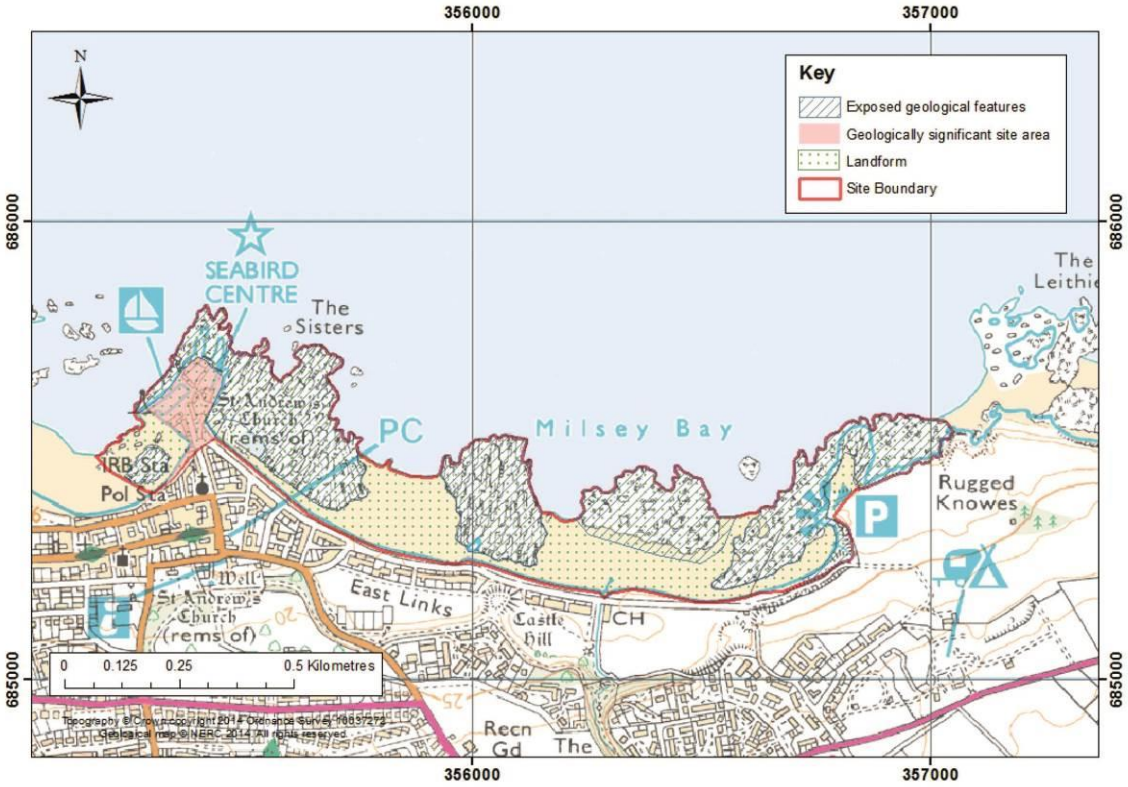


Figure 10: North Berwick Shore Location Map. The site comprises rocks exposed in shore platforms with intervening areas of beach. The exact area of bedrock exposure (blue hatched areas) is likely to vary in time due to changes in the beach morphology. Areas of geological significance include a viewpoint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

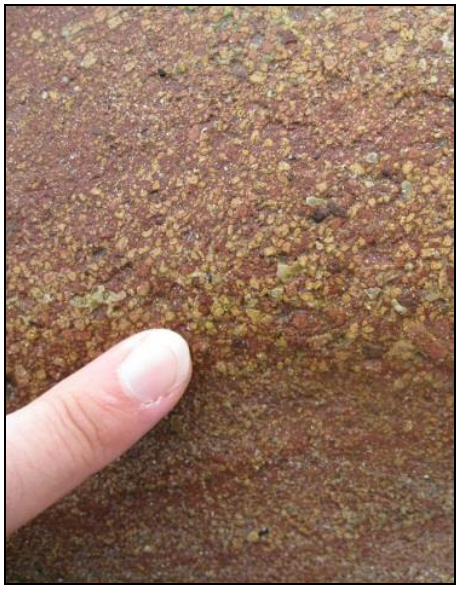


Photo ELC_5 P3: The calcareous mudstones contain tuffaceous layers, representative of ash-rich volcanic eruptions over the shallow lagoonal environments forming the calcareous mudstones. These tuffaceous layers are clast –supported, and composed of sub-angular clasts of creamy, altered feldspar crystals,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

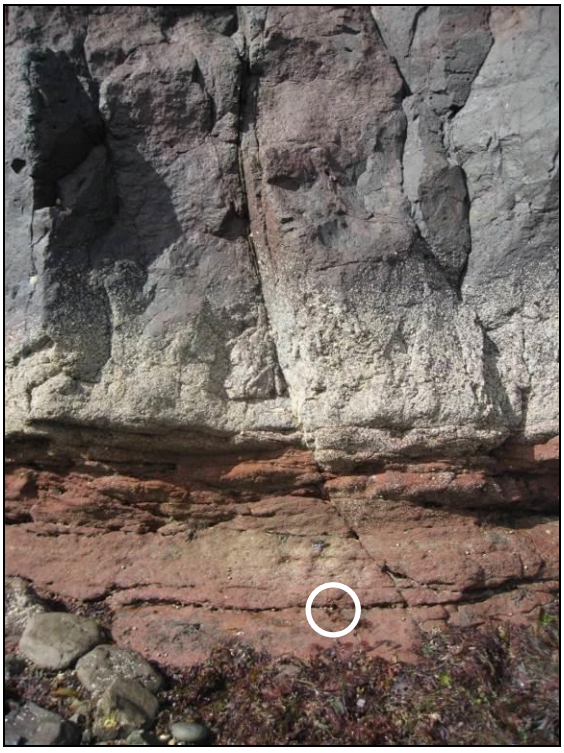


Photo ELC_5 P15: A 10 cm displacement normal fault cutting the 'Dunsapie' basalt and red tuff layer is exposed in the intertidal zone below the Sea Bird Centre. The plane of the fault is near vertical in the overlying basalt, and as it dissects the tuff becomes more inclined. This 'refraction' of the 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

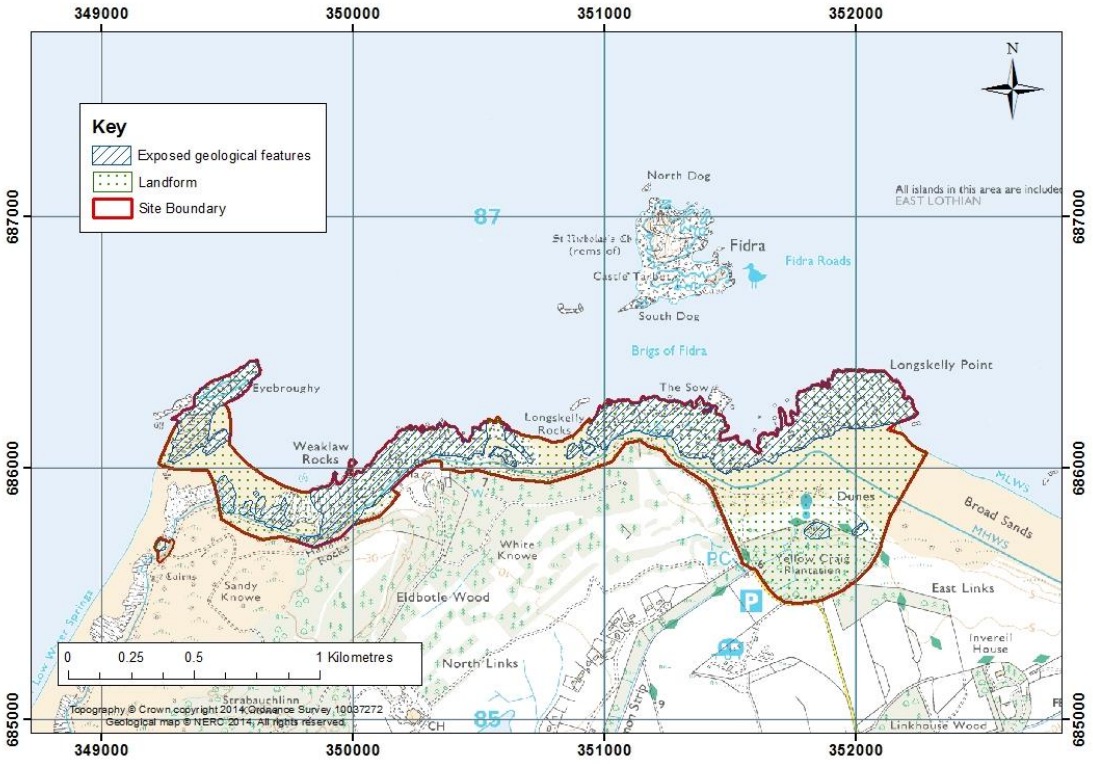


Figure 11: Yellow Craig Shore Location Map. Bedrock exposure (blue hatched areas) is likely to vary over time due to changes in beach morphology. Coastal landforms, including wave-cut platforms, dunes and areas of beach in the immediate vicinity of the main rock outcrops are included within the site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

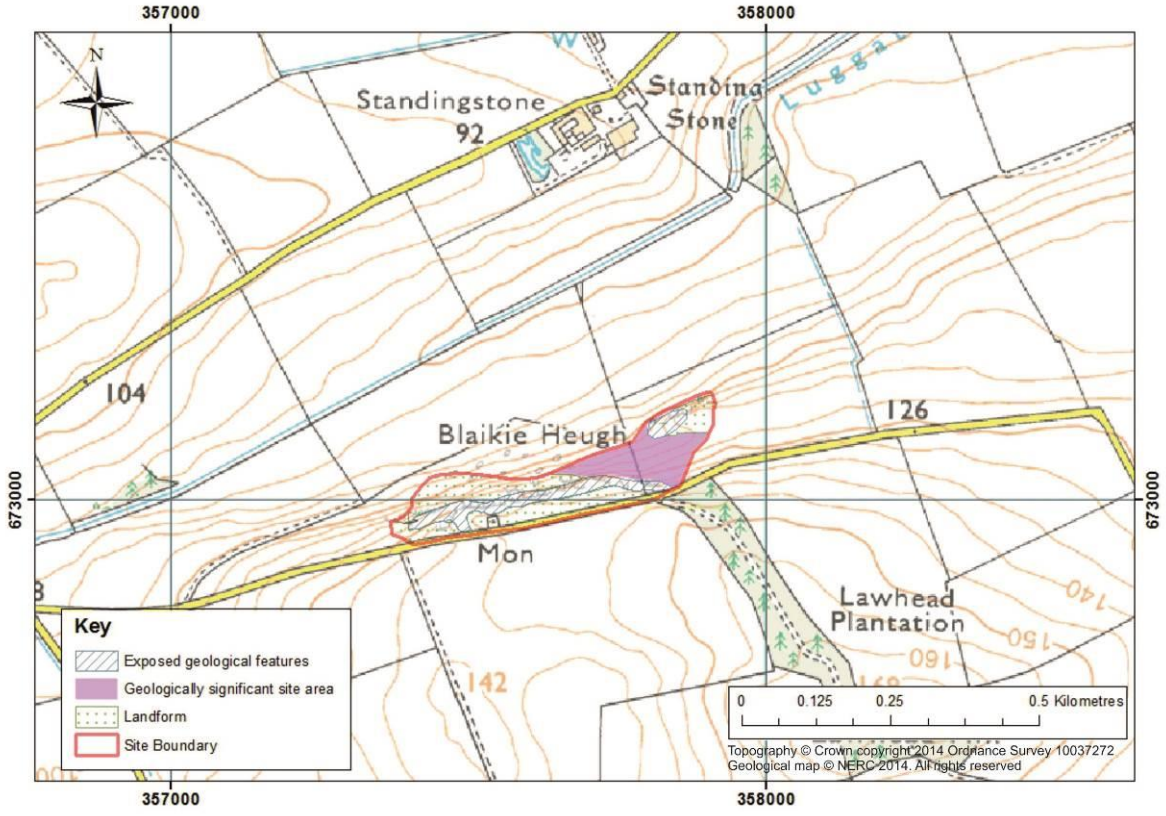


Figure 13: Blaikie Heugh Location Map. The site boundary includes rock and landforms including boulder fields lying at the base of the cliff, the cliff escarpment and streamlined bedrock. The area between the two rock exposures is classed as geologically significant for access between the sites and for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

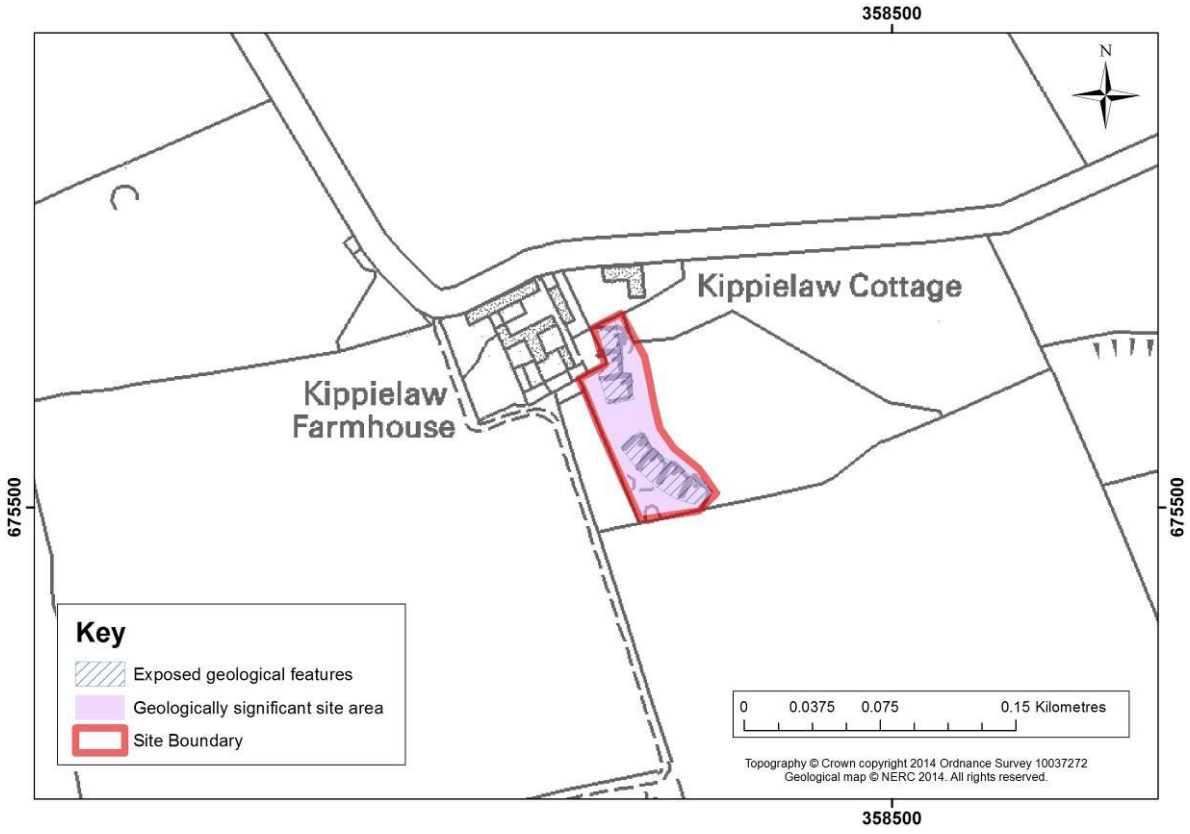


Figure 14: Kippielaw Scarp Location Map. The site boundary has been drawn to include key exposures, and access to the site as well as suitable viewing distance of the natural surfaces (geologically significant area).

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

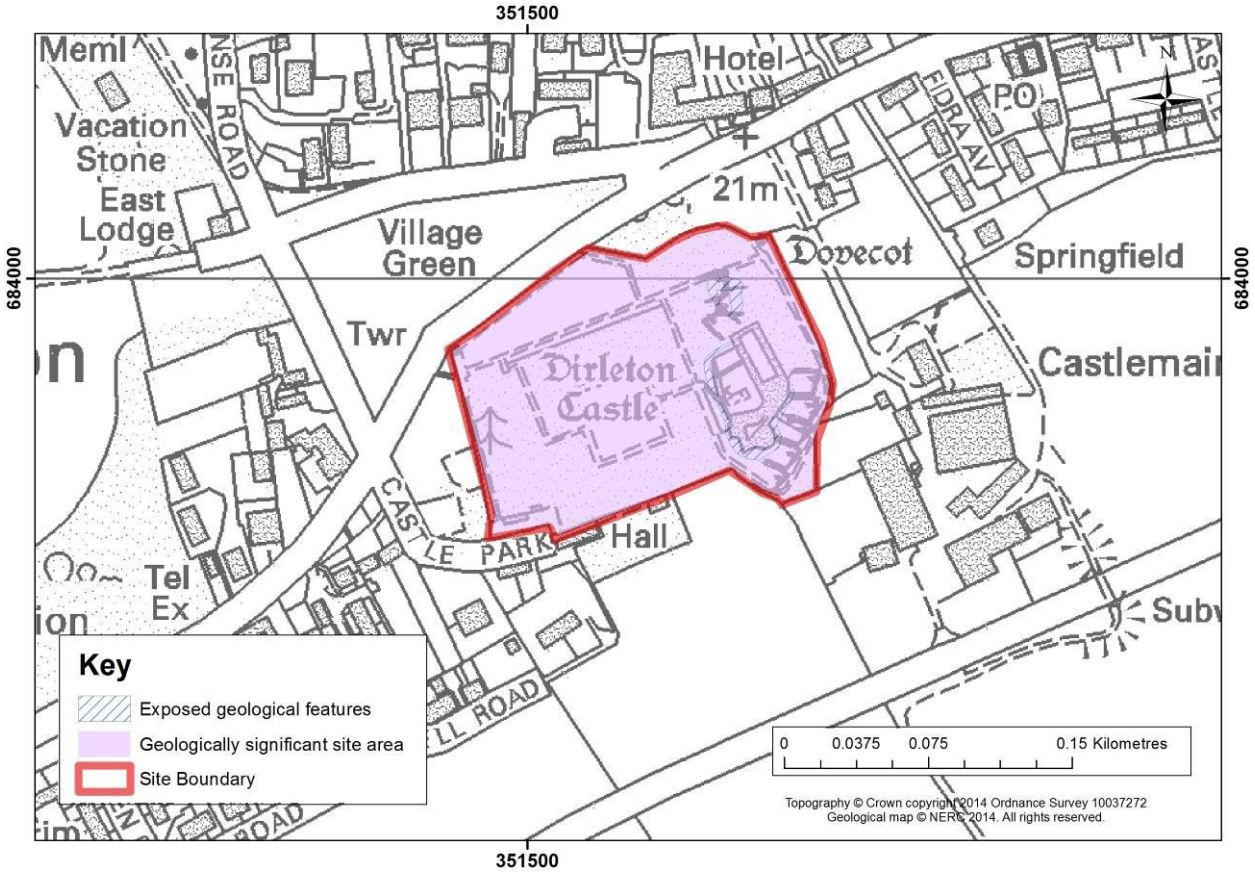


Figure 15: Dirleton Castle Location Map. The site boundary is drawn to include key exposures, access to the castle and grounds and coincides with the area of the Scheduled Ancient Monument. The castle itself is also considered to be part of the geologically significant area associated with the site.

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.

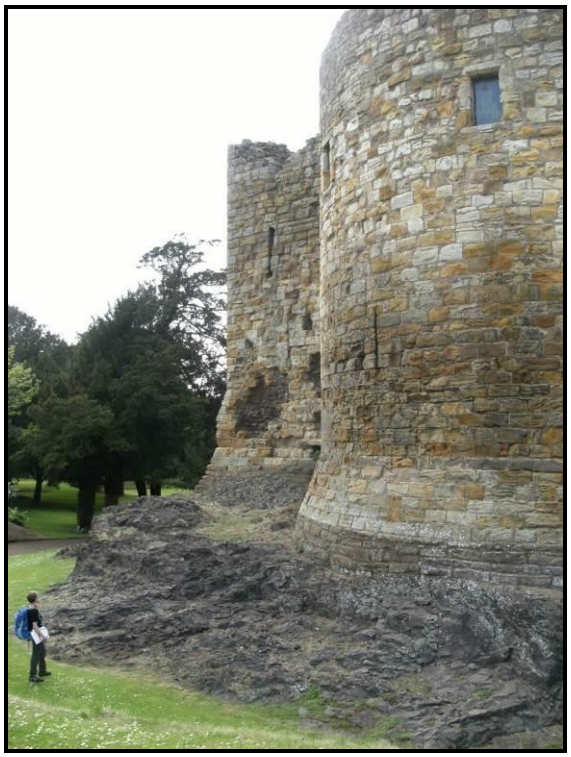


Photo ELC_10 P4: The trachyte is more blocky in appearance to the south and west of the site. © BGS, NERC.

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

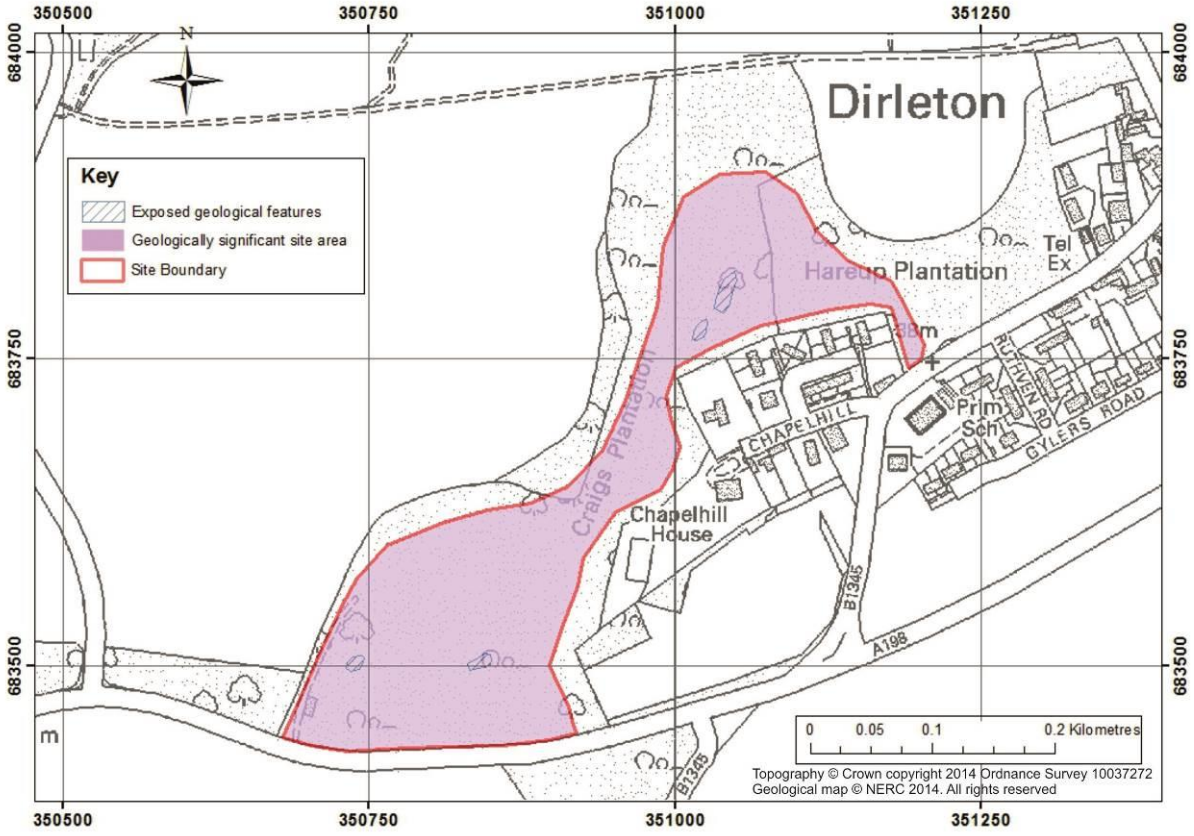


Figure 16: Craigs Quarry Location Map. The site boundary includes small areas of rock exposure, with a larger geologically significant area that incorporates the location of the old Craigs Quarry, and access paths to the site.

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

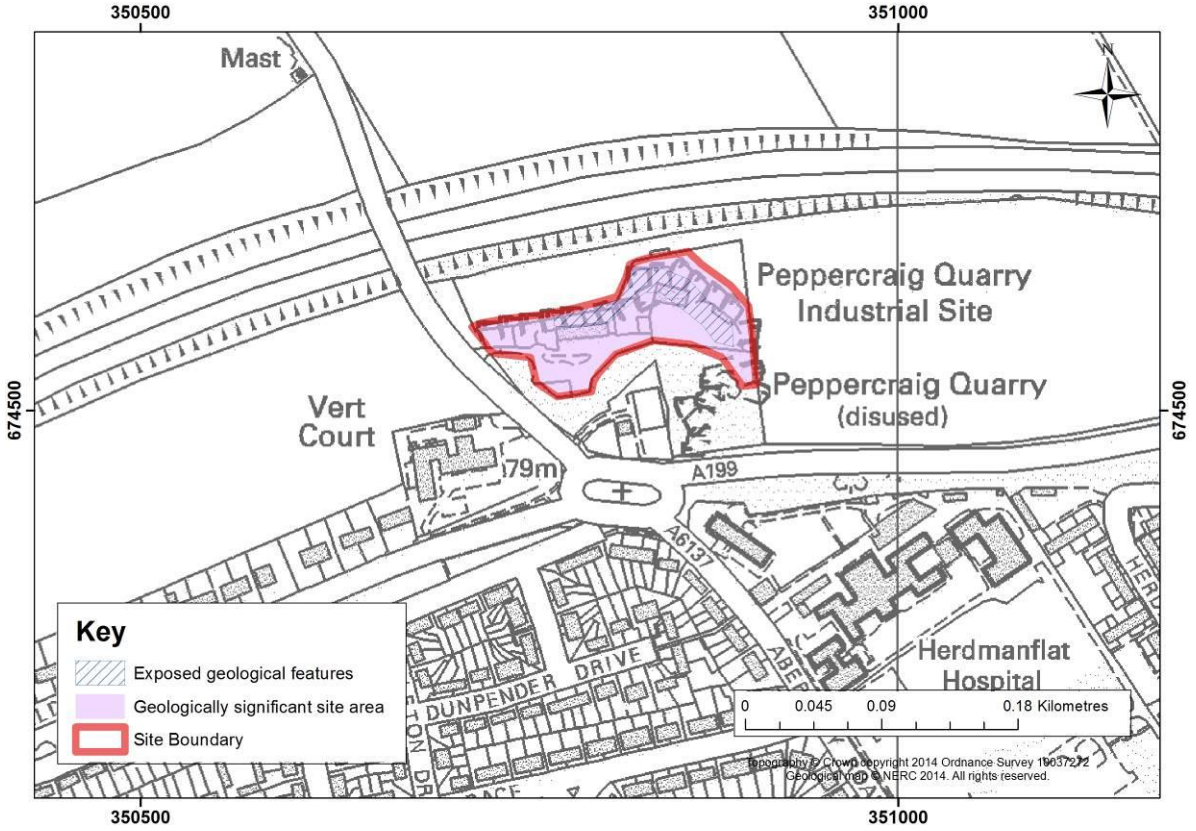


Figure 17: Peppercraig Quarry Location Map. The site boundary includes the original extent of the quarry, which is historically and geologically significant due to its importance in providing building stone to the town of Haddington. Exposed rock is highlighted by blue hatched areas.

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

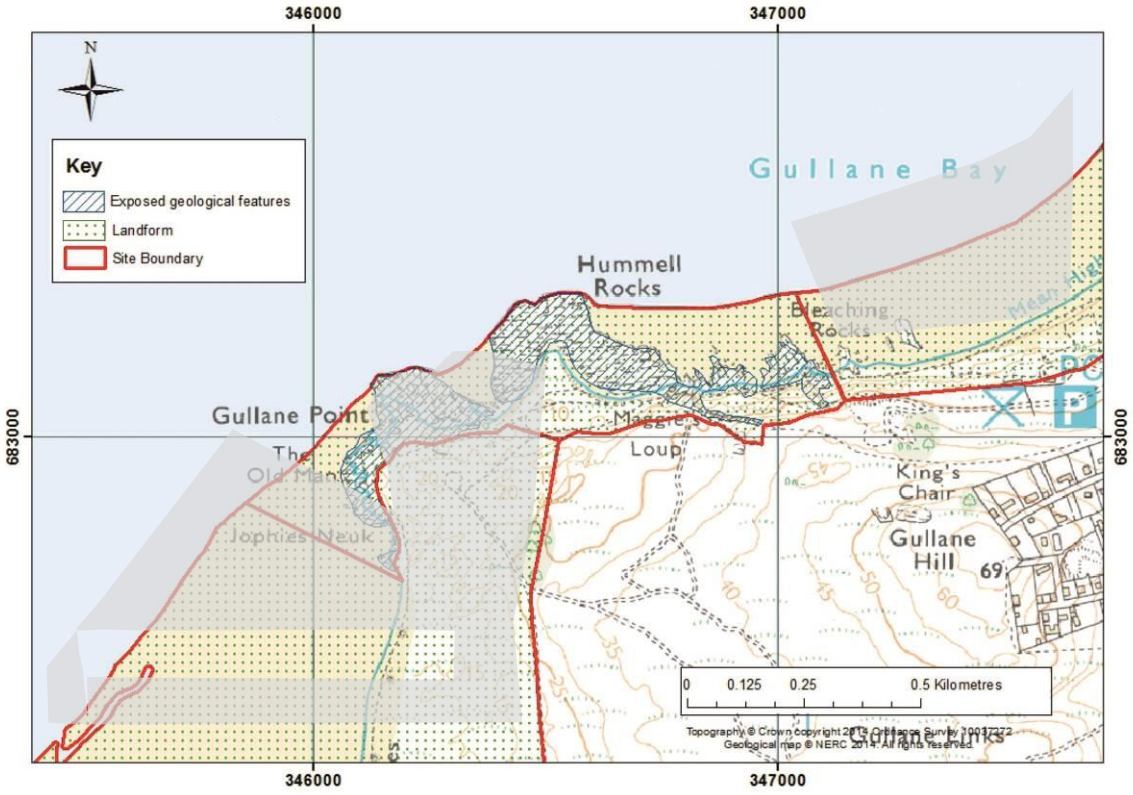


Figure 18: Gullane Shore Location Map. The site area comprises bedrock exposures in shore platforms and coastal landforms including inlets and areas of beach in the immediate vicinity of the main rock outcrops**,** The exact area of bedrock exposure is likely to vary in time due to changes in the beach 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

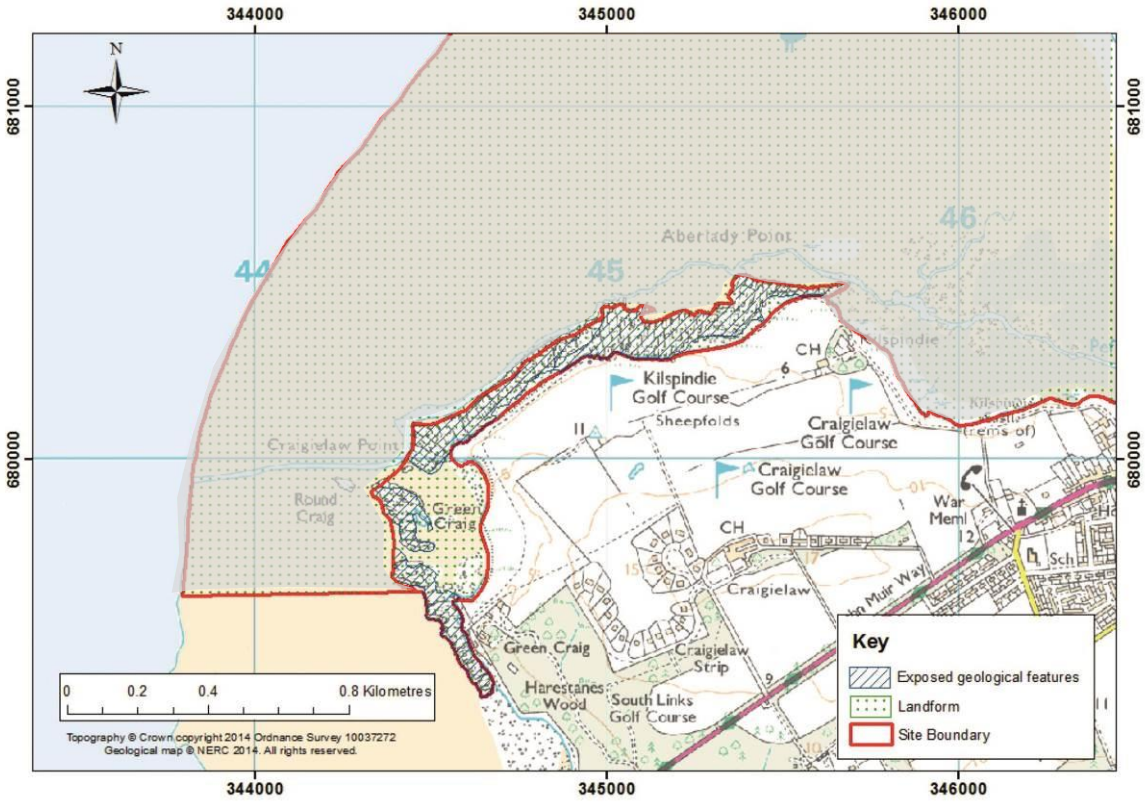


Figure 19: Kilspindie Shore Location Map. The site boundary is drawn to include access along the edge of Kilspindie Golf course, as well as encapsulating local landforms (e.g. beaches) and the key rock exposures. This site is immediately adjacent to the geomorphological Aberlady Bay Site (ELC_30). The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