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Geodiversity Audit of Spireslack and Mainshill Wood Surface Coal Mines

Geology and Landscape Scotland Programme

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BRITISH GEOLOGICAL SURVEY

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Geodiversity Audit of Spireslack and Mainshill Wood Surface Coal Mines

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Keywords

Spireslack Surface Coal Mine, Mainshill Wood Surface Coal Mine, Geodiversity, Carboniferous, Coal.

Front cover

Spireslack SCM main void (above) and Mainshill Wood SCM (below). © BGS/NERC

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Foreword

The Spireslack and Mainshill Wood surface coal mines (SCM) in Scotland reveal spectacular exposures of Carboniferous strata on a scale not seen anywhere else in the United Kingdom. In order to recognise and protect the wide range of geological features across each mine, and to assess their status as National Assets, the Scottish Mines Restoration Trust (SMRT) commissioned the British Geological Survey (BGS) to audit and assess the geodiversity of each of these sites.

This report, produced by the BGS, is a systematic inventory and evaluation of geodiversity sections and sites within Spireslack and Mainshill Wood SCMs. This audit has the potential to help inform future development and planning decisions of each site, in particular with respect to the protection of each site's geodiversity. It also provides an information resource to support education, and management activities that promote the preservation of geodiversity sites and geological resources.

Acknowledgements

The authors wish to express their thanks to Robin Caldow and Kenny Ewart (both acting on behalf of SMRT) for access to the sites for field auditing, Mike Browne (Honorary Research Associate, BGS) for sharing his in-depth and insightful knowledge of the geology of the sites, and to Diarmad Campbell (BGS) for his advice and input to this report.

Maps and diagrams have been prepared by the authors, except where stated.

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Summary

This report describes a geodiversity audit of the Spireslack and Mainshill Wood surface coal mines (SCM) carried out by the British Geological Survey (BGS) on behalf of the Scottish Mines Restoration Trust (SMRT).

For the present study, in order to place the geodiversity of the two SCMs in context, BGS records and published sources of the surrounding geology were reviewed, including digital geological maps and historic field slips, digital aerial photography, and published papers, memoirs and reports. Documentation for nearby sites already recognised as Sites of Special Scientific Interest (SSSI) and/or Geological Conservation Review (GCR) sites was also reviewed.

Field assessments of sections within Spireslack were conducted in August 2015. Due to flooding restrictions, access to Mainshill Wood was not possible. Therefore, data from previous field visits and photography by BGS geologists are used within this report to document sites of geodiversity value there. Geoscientific merit of individual sites within Spireslack was evaluated in terms of the rarity and quality of the key features displayed at the site, according to well-established procedures.

Spireslack and Mainshill Wood SCMs provide spectacular exposures of Carboniferous strata not otherwise seen naturally on anything approaching the same scale or completeness across the whole of Scotland, or further afield in the UK. As such, they are of national significance. A total of 18 sections were identified as candidates for recognition and protection as local geodiversity sections within Spireslack, whilst the whole of the remaining void within the south-western corner of Mainshill Wood is presented as a geodiversity site worthy of protection. The sections selected include the best examples of geological features within each surface mine and are considered to be representative of the diverse range of geological strata and structures that characterise the geology of these sites and the wider surrounding area. It is recommended that these sections within Spireslack and Mainshill Wood should be protected and preserved during any subsequent development of the surface mine workings.

Many of the identified sections of local geodiversity value have the potential to be enhanced through interpretation on site to inform visitors and students at all levels about geology, and the links they have with the local economic and cultural heritage within East Ayrshire and South Lanarkshire, and the Central Belt of Scotland as a whole. These sites also offer opportunities to the research community, to generate a wide spectrum of internationally significant teaching and strategic research activity.

Whilst Spireslack and Mainshill can be considered as ‘flagship’ sites in terms of their spectacular exposures of complete stratigraphic sequences and unique structural geology preserved within them, they also form part of a subset of inactive and active surface mine sites across East Ayrshire and South Lanarkshire. Collectively, and in the longer term, this network could form the basis for a potential Geopark across the south-western Central Belt of Scotland.

1 Introduction

The British Geological Survey (BGS) was commissioned by the Scottish Mines Restoration Trust (SMRT) to carry out a geodiversity audit of sections of particular geological significance within the abandoned surface coal mines of Spireslack and Mainshill Wood, in East Ayrshire and South Lanarkshire respectively. Both surface coal mines (SCM) have revealed spectacular sections through coal-bearing Carboniferous strata (Patterson et al, 1998) worthy of preservation and/or stewardship for future generations. Mainshill Wood SCM, situated just off the M74 near Happendon Services, reveals outstanding structural geology linked to the major Kennox Fault within the Clackmannan Group (BGS 1: 50 000, 23E (Lanark) published geological map), whilst Spireslack SCM, located north of the A70 at Glenbuck, has exposed a world class 1.5 km long section through the whole of the Limestone Coal Formation (BGS 1: 50 000, 23W (Hamilton) geological map). The geology revealed at both sites exposes structures and strata not typically seen on anything approaching the same scale or completeness/continuity within natural sections across Scotland, or further afield in the UK. They thus provide unique and important insights into the character of key Carboniferous strata. They also preserve important examples of Scotland's coal mining legacy: for example, Spireslack SCM reveals sections cut through an earlier generation of underground workings allowing an appreciation of the ways and respect for the conditions under which, those early coal miners worked.

This study has taken the form of a systematic geodiversity audit within each site to assist in future planning, development and conservation of the two sites. The audits were carried out using well established assessment procedures based on other regional BGS geodiversity audits (e.g. Arkley, 2011; Barron et al., 2005; Whitbread and Arkley, 2013; Whitbread et al, 2015). The audits are placed in the regional geological context of the area to aid wider development opportunities, such as potentially Geopark status for the Coalfields across East Ayrshire and South Lanarkshire.

This work was undertaken in August and September 2015 with a desktop-review of BGS records and published literature followed by field visits to gather new geodiversity information. This report describes, illustrates and evaluates key geological sites within the Spireslack and Mainshill Wood SCM voids that are considered to best represent the geological diversity of the sites. The audit of Spireslack and Mainshill Wood SCMs is intended to form the basis for recognition and protection of local geodiversity sections within the surface mines. The audit will also provide SMRT with information that may be used to enhance the quality of the geological assets at the two sites and to develop public engagement and education initiatives.

Recommended boundary lines defining the site areas have also been supplied separately to SMRT in GIS format (ESRI Shapefile) to supplement the information provided in this report.

1.1 AIMS AND OBJECTIVES

The principal aim of the study is to identify and formally assess the key geodiversity sections within the Spireslack and Mainshill Wood surface coal mines (based on methodologies developed in Arkley, 2011; Barron et al., 2005; Whitbread and Arkley, 2013; Whitbread et al, 2015). These sections are selected to represent the diverse geology of the site.

The objectives of the study are:

1. to evaluate the geodiversity of each surface coal mine based on criteria that consider the scientific, educational, and cultural merits;
2. to delineate section boundaries that encompass the key geological features of the surface coal mines and sufficient area to allow them to be viewed;

3. to review the condition of the sections and, where appropriate, to make suggestions for potential improvements in the management, access and educational potential of the section.

1.2 STRUCTURE OF THE REPORT

An overview of the geology of, and surrounding Spireslack and Mainshill Wood is presented in Chapter 2, including the bedrock (solid) geology and briefly, the overlying Quaternary (superficial) deposits. Chapter 3 describes the methods used to identify potential geodiversity sections, 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 sections within Spireslack SCM, followed by a description of the geodiversity site at Mainshill Wood SCM: this chapter forms the main part of the report. The results of the audit are summarised and discussed in Chapter 5.

1.3 WHAT IS GEODIVERSITY?

Geodiversity has many definitions (e.g. Gray 2005; Crofts 2014), 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 our natural environment, but also the character of local wildlife habitats and ecosystems.

Geodiversity underpins the social, cultural and economic heritage of an area. The locations of settlements, abstraction of coal and other resources give a distinct character to the region and typify the close links between our human heritage and our geodiversity.

1.4 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 in Scotland. Current protection for geological sites in Scotland is restricted to the sites that are designated as ‘Sites of Special Scientific Interest’ (SSSIs) by Scottish Natural Heritage (SNH).

Awareness of other important geological sites was formally initiated in 1977 with the launch of the Geological Conservation Review (GCR). The GCR was developed to identify sites of national and international importance which underpinned the key scientific elements of Earth heritage in the UK (http://jncc.defra.gov.uk/). The aim of the review was to provide a publically available record of these sites, which were already notified or being considered as SSSIs. The chosen GCR sites form ‘the basis of statutory geological and geomorphological site conservation in Britain’ (http://jncc.defra.gov.uk/), and were picked with the view to their long-term conservation. GCR sites which did not achieve SSSI status, or indeed, SSSI sites which lost their status, may form part of Regionally Important Geological/Geomorphological Sites (RIGS) schemes, part of GeoConservationUK. GeoConservationUK formed ‘to promote local ‘geo’ sites for education and public benefit’ (http://wiki.geoconservationuk.org.uk/). Whilst these sites do not benefit from national statutory protection, they are recognised by the local authority and listed in their development plans (http://wiki.geoconservationuk.org.uk/). In Scotland these sites are called ‘Local Geodiversity Sites’.

Scotland also has its own dedicated charter – the first of its type in the world – to raise awareness of geodiversity and integrate it into policy and decision making – ‘Scotland’s Geodiversity Charter’. This Charter is supported by the Scottish Government, The British Geological Survey and SNH, along with a large number of other stakeholders (http://scottishgeodiversityforum.org/charter).

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, and features within an urban environment may be built over. 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 Geological Background

In the following review of the bedrock and superficial (Quaternary) geology of Spireslack and Mainshill Wood, information was derived from the published geological maps of the area; BGS 1: 50 000 scale map sheets 23W (Hamilton) and 23E (Lanark), and the geological memoir for Hamilton (Patterson et al., 1998) and Lanarkshire: Central Districts (Geikie A, 1873).

Spireslack and Mainshill Wood SCMs lie within the Central Belt of Scotland, situated between the Highlands to the north and the Southern Uplands to the south (Figure 1). These geographical boundaries are driven by the underlying geology: the Highlands are predominantly composed of metamorphic rocks of Precambrian age, separated from the geological entity of the Midland Valley by the Highland Boundary Fault. The Southern Uplands, predominantly composed of sedimentary rocks of Silurian and Ordovician age, are separated from the Midland Valley by the Southern Upland Fault. The down-faulted region of the Midland Valley (essentially occupying the same area as the Central Belt of Scotland) between these two major faults consists mainly of Carboniferous and Devonian rocks (Figure 1) overlying Lower Palaeozoic rocks.

Carboniferous sedimentary rocks in the Central Belt of Scotland have played a strategic role in industrial development across the region, providing key resources such as coal, ironstone, oil shale, sandstone and limestone, formed when Scotland lay in warm and tropical equatorial latitudes around 358 to 303 million years ago. The Carboniferous rocks exposed at Spireslack and Mainshill Wood SCMs are Viséan to Namurian in age (around 330 to 325 million years old), and in order of oldest to youngest (see Figure 2), belong to the Lawmuir Formation of the Strathclyde Group and the Lower Limestone, Limestone Coal, Upper Limestone and Passage formations of the Clackmannan Group (Browne et al., 1999). Typical Carboniferous rock sequences exposed at each site show cycles of environmental change, from shallow tropical seas (recorded in marine limestones and mudstones), to delta development and river channels (recorded in siltstones and sandstones), tropical soil (preserved as rooted seatearth) and finally tropical swamp forest (preserved as coal). Ironstones formed in anoxic conditions in lakes and soils, whilst marine incursions are recorded by marine bands (e.g. the Johnstone Shell Bed and Black Metals Marine Band).

The strata exposed at Spireslack SCM (Figure 3) form the north-western limb of a broad upright north-east trending syncline, and as a result dip moderately steeply at around 30 to 40 degrees towards the south-east in the main void. The rocks here are also displaced in a mostly left-lateral (or sinistral) direction by a number of oblique-slip faults. Palaeogene basaltic dykes intruded these inclined strata at Spireslack SCM around 60 million years ago. In contrast, at Mainshill Wood SCM (Figure 4), the strata are sub-vertically inclined, probably in response to deformation associated with the north-east trending Kennox Fault. The southern limit of coal extraction in the main void at Mainshill Wood SCM is taken at the Kennox Fault, where the Carboniferous strata reveal a complex flower structure formed within the Kennox Fault Zone.

Quaternary deposits consisting of grey-brown glacial till (approximately 2 – 3 m thick) and dark brown-black peat (< 2 m thick) cover the strata at and around the Spireslack SCM. A reddish-brown 2 – 3 m thick glacial till overlies the strata at Mainshill Wood SCM. Glacial till was deposited by ice sheets which covered Scotland during the last Ice Age, the last main phase of which ended approximately 10 – 12 thousand years ago. The colour of the till is often associated with the underlying rock types. As Scotland became warmer, these glacial deposits formed primitive soils allowing vegetation growth which, over time, formed peat. Peat formation is linked to prolonged periods of increased precipitation, where the soil becomes permanently waterlogged and decomposition of plant matter is restricted, allowing thick expanses of peat to form.

Man-made (or made ground) deposits cover both the bedrock and superficial deposits at the two surface coal mines. Whilst Spireslack's earlier phase of mining occurred underground in the

19th/20th century, bell-pits constructed during the late 1700s are visible on the surface at the south of Spireslack. At both Spireslack and Mainshill Wood, tens of metres thick mined waste covers the pre-existing ground surface, related to the late 20th to early 21st century surface mine operations.

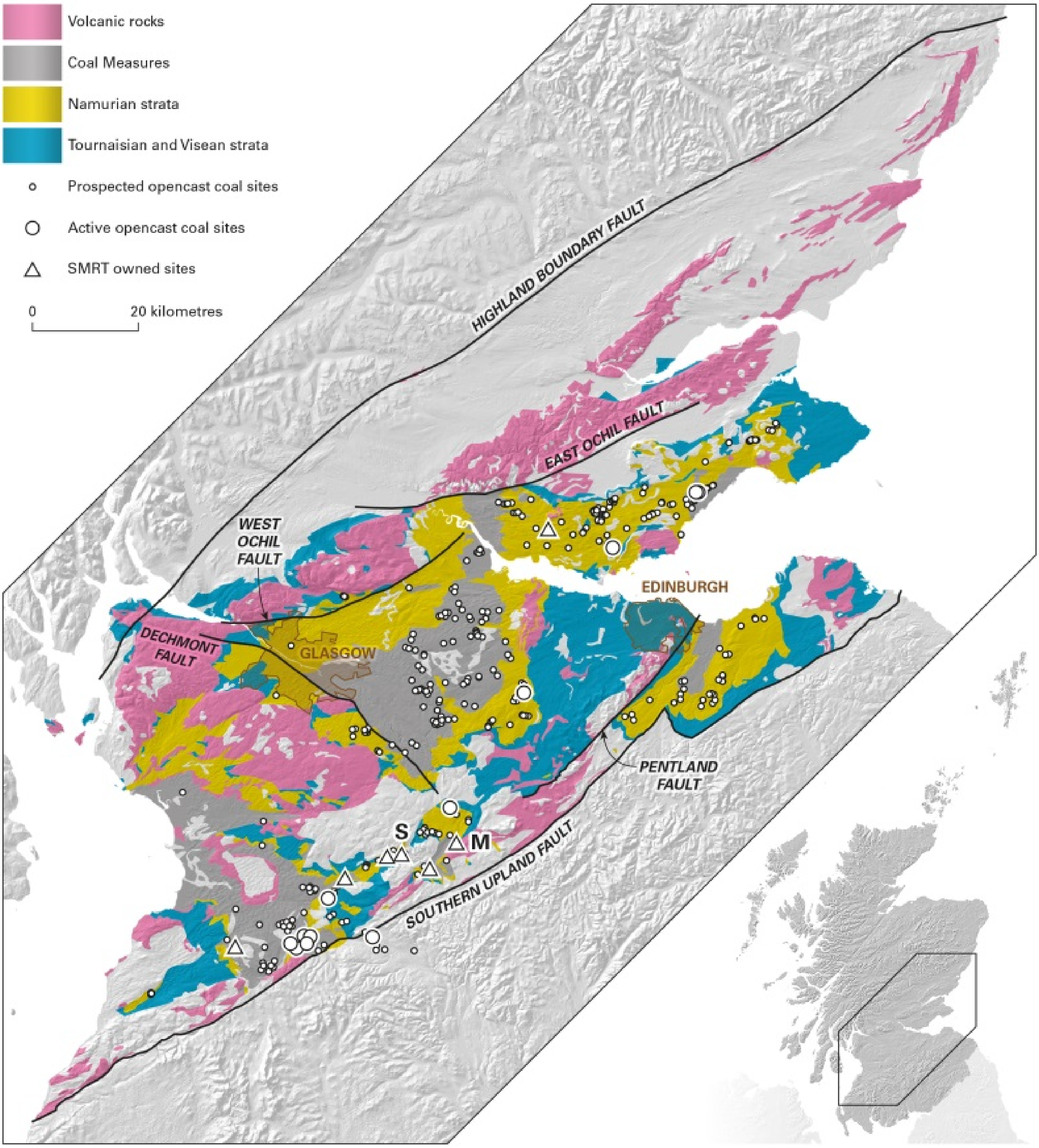


Figure 1: Generalised Carboniferous geology of the Midland Valley of Scotland, showing the major faults that bound the Midland Valley. The map also shows the locations of prospected and active surface coal mines in Carboniferous strata. Sites owned by the Scottish Mines Restoration Trust (SMRT) are also indicated, with the locations of Spireslack (S) and Mainshill Wood (M) SCMs highlighted.

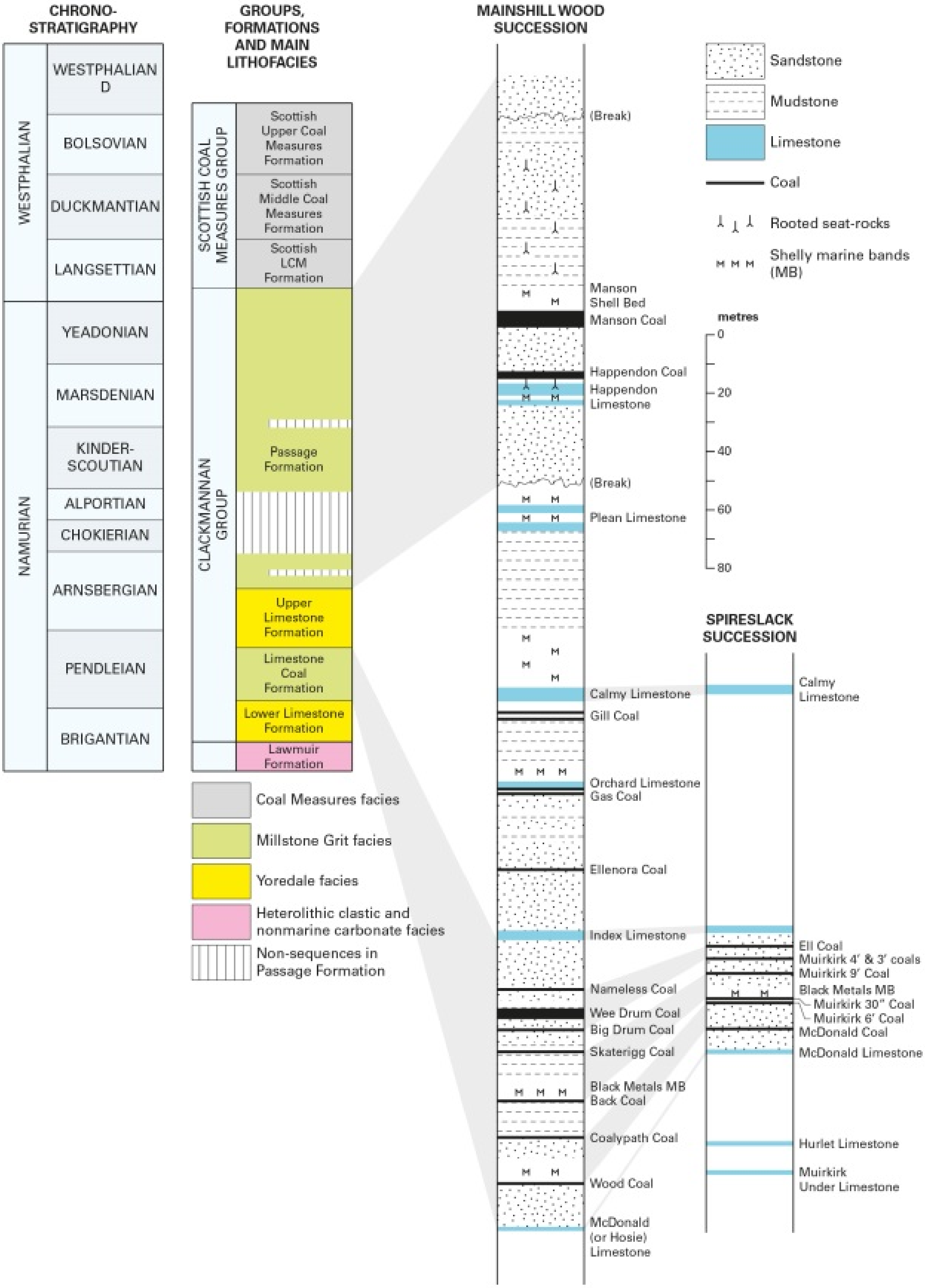


Figure 2: Stratigraphical framework for coal-bearing strata at Mainshill Wood and Spireslack SCMs. The key coal units and lithological markers referred to in this audit are highlighted in the more detailed columns.

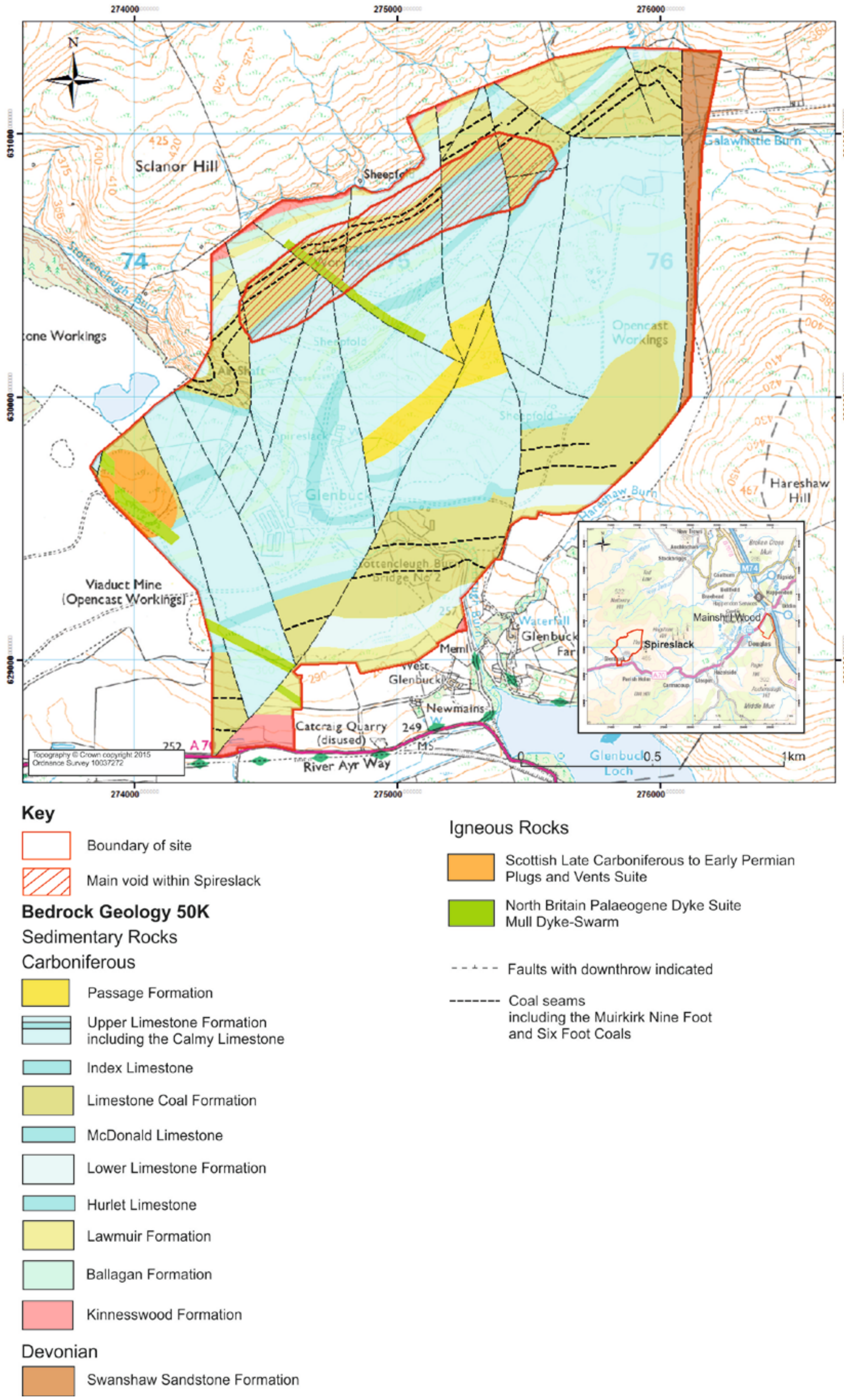


Figure 3: 1:50 000-scale geological map within the Spireslack SCM site area. The oldest rocks within the site are exposed at the far east of the site boundary, and are sandstones belonging to the Swanshaw Formation (Devonian in age). These rocks are separated from the Carboniferous rocks by a major north-trending fault. The Carboniferous strata have been folded into a broad north-easterly syncline across the site, with the strata offset by many faults with a dominant north to north-north-easterly trend.

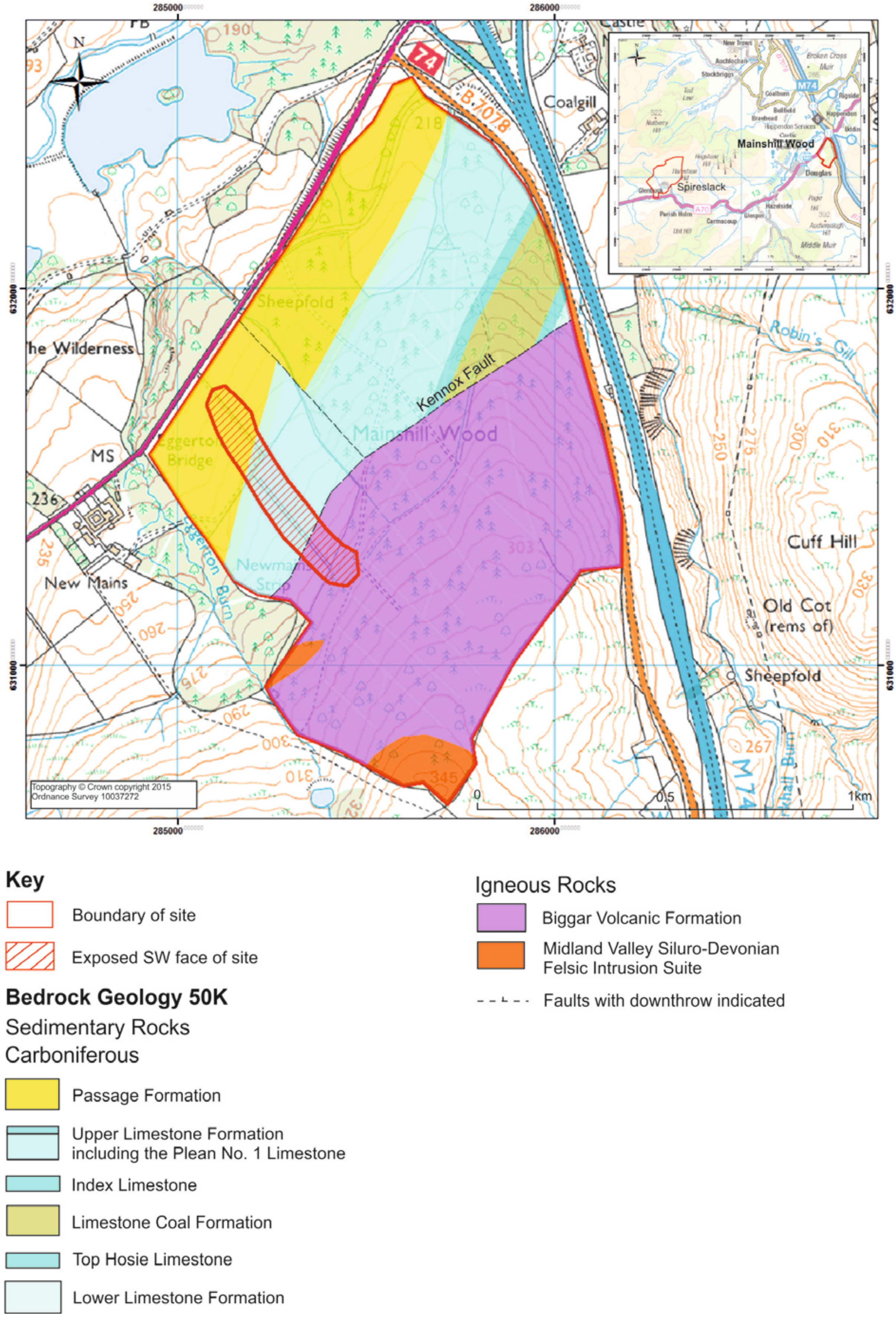


Figure 4: 1:50 000-scale geological map within the Mainshill Wood SCM site area. The oldest rocks within the site belong to the Devonian age Biggar Volcanic Formation, situated to the south of the Kennox Fault in the southern portion of the site. The Carboniferous strata lie to the north of the Kennox Fault where they are sub-vertically arranged. The rocks become younger towards the north.

2.1 GEOLOGICAL CONSERVATION REVIEW AND SSSI SITES

Spireslack and Mainshill Wood SCMs lie within close proximity to eleven Sites of Special Scientific Interest (SSSI) and six Geological Conservation Review (GCR) sites (see Figure 5). There are six geological SSSI's surrounding the two SCMs, with the remainder designated for biodiversity. The geological SSSI's also form the GCR sites.

The GCR was initiated by the Nature Conservancy Council in 1977 to identify and describe the most important geological sites in Great Britain, and these designated sites form the basis of statutory geological and geomorphological site conservation in the UK. The GCR sites near Spireslack (Ree Burn and Glenbuck Loch and Shiel Burn) are of Silurian age, older than the rocks exposed within the SCM. Shiel Burn is globally significant due to its rich and rare fauna of Silurian fish fossils, whilst Ree Burn and Glenbuck Loch are of importance for exposures of Silurian stratigraphy (Aldridge et al., 2000; Cossey et al., 2004; Dineley and Metcalf, 1999).

These designated and recognised natural geological sections show that this area of Scotland is rich in geological heritage, and is of national, and indeed, international geological importance. Combining these protected sites with the spectacular Carboniferous exposures at Spireslack and Mainshill Wood SCM would not only add to the area's strong geological importance and provide a protected rock record spanning over 100 million years' worth of geological history (from the Silurian to the Carboniferous era), but it would also link national industrial heritage to the area's geological heritage: thus strengthening the case for potential future Geopark status in this part of Scotland.

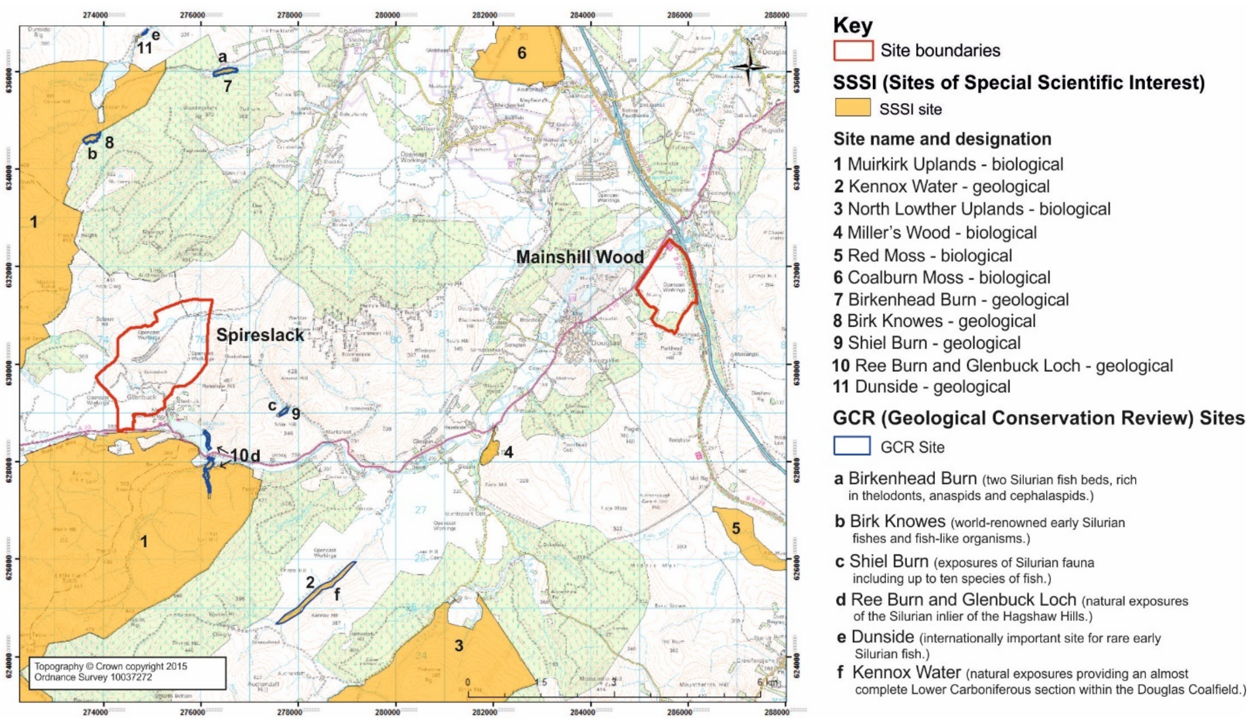


Figure 5: Map showing locations of nearby SSSI and GCR sites in the areas neighbouring Spireslack and Mainshill Wood SCMs.

3 Geodiversity Audit

3.1 SPIRESLACK SURFACE COAL MINE

In 2007, the main linear void within the northern part of the Spireslack SCM was proposed by its operators as a local geodiversity site following discussions with the Strathclyde Geoconservation Group, GeoConservationUK, East Ayrshire Council and the British Geological Survey. Whilst this canyon within Spireslack is arguably worthy of geodiversity and conservation status in its own right, there are several important geological features internally within it, and also across the rest of the Spireslack SCM, which deserve protection in the event of site development (Figure 6). If these key features were covered or destroyed by subsequent development, it would be a detrimental loss to the overall value of the site. Thus, the following audit sites, referred to here as 'geodiversity sections' describe these key features in detail. Their protection should be prioritised (and where appropriate enhanced) in any future development of Spireslack SCM. See Appendix 1 for additional geological features of interest which have limited exposure and access and are therefore not described as a key geodiversity section, but provide an important adjunct from a research or general interest point of view. The sites in the appendix should be considered as a second priority for protection than those included in the main audit.

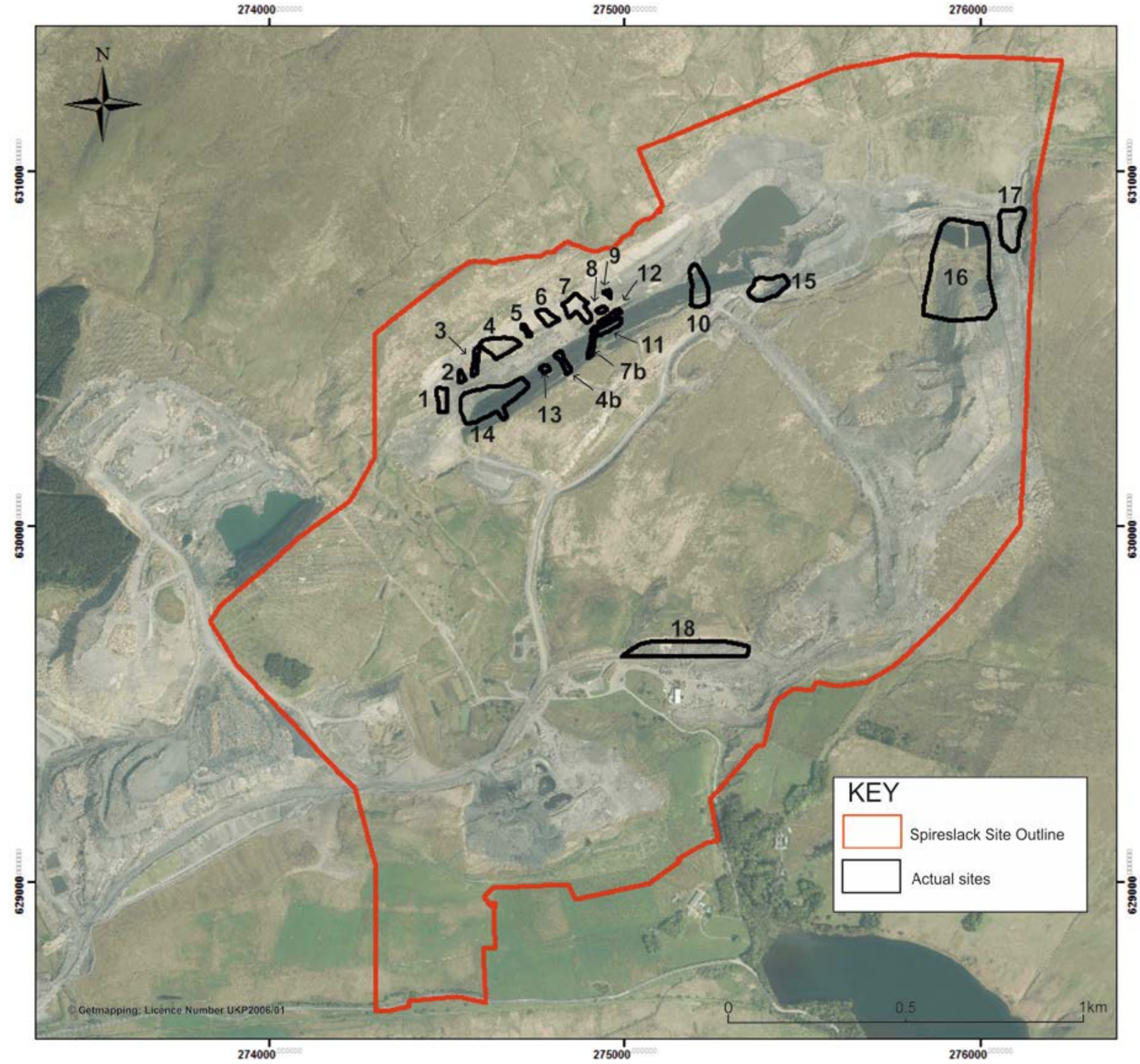


Figure 6: Aerial view of Spireslack SCM, showing locations of the audited geodiversity sections within the mine. The number of the site corresponds with the equivalent audited site described in the report.

3.2 SPIRESLACK AUDIT METHODOLOGY

Geodiversity sections throughout Spireslack SCM were selected on the basis of their key categories of geological interest, rarity within Spireslack, and quality within Spireslack. Geodiversity sections may only have one key geological interest category whilst others can comprise an amalgam of several aspects. The key categories of geological interest include:

- **Sedimentary rocks**: features related to depositional processes and settings
- **Stratigraphy**: features indicative of an important stratigraphic horizon and helping to define the sequence of geological strata
- **Palaeontology**: fossils or trace fossils
- **Igneous rocks**: features relating to intrusive igneous rocks
- **Structural geology**: faults, folds, fractures or other deformation features
- **Mineralisation**: mineral vein deposits
- **Quaternary deposits**: features representative of depositional processes on the Earth's surface
- **Economic geology**: features relating to man-made structures and processes
- **3D visualisation**: a combination of 2D views which provide a 3D appreciation of geology

Rarity was assessed on a local basis in relation to how many examples of the key geological interest there were within Spireslack. A one star rating demonstrates there are many examples of the key interest throughout the site, whereas a 5 star rating demonstrates it is the only example. Quality was assessed on the basis of how well preserved the feature is within Spireslack, with a one star rating illustrating average preservation (e.g. overgrown, covered in spoil, eroding, difficult to visualise) and a five star rating demonstrating exceptional preservation (e.g. geological features very easy to see, and easily accessible).

3.3 SPIRESLACK GEODIVERSITY AUDIT

The following section comprises individual geodiversity section description and evaluations, and is presented as a set of pro-forma sheets containing:

- A summary table classing the key features of geological interest, with a rarity and quality rating in the context of Spireslack;
- A location map (with the site highlighted in yellow amongst their neighbouring sites, drawn in black), and digitised proposed site protection boundary;
- A description of the key geological features in each geodiversity section;
- A review of the access and site enhancement potentials for each site;
- Site photographs

The term 'scarp' is employed throughout the text for the striking rock scarp, created during surface mining, that forms the high back wall at the southern side of the main Spireslack void.

Across all sections audited, a recommended site enhancement is the addition of interpretation boards to explain the geological features.

Where appropriate, observations have been made on the current condition of the site but no assessment of stability has been made. Stability should be assessed by suitably qualified personnel.

Spireslack Locality 1: Lawmuir Formation	**NGR:** [274486 630365] - [274487 630330]

Key categories of interest	Rarity	Quality
1. Stratigraphy	★★★★	★★★★
2. Palaeontology	★★★	★★★★
3. Sedimentary rocks	★	★★
4. Mineralisation	★★★	★★
5. Structural geology	★	★

Access: Good access from roadway, but best viewed from a distance.
Current safety: Loose blocks and scree above locality, uneven surfaces underfoot.
Measures to enhance site: Flatten area in front of exposure.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of Locality 1. Site boundary includes key rock exposures, immediate access to site and potential viewing points to the site. Photo looking to the west, taken from above the scarp looking down on to site.

Site Description

Geology

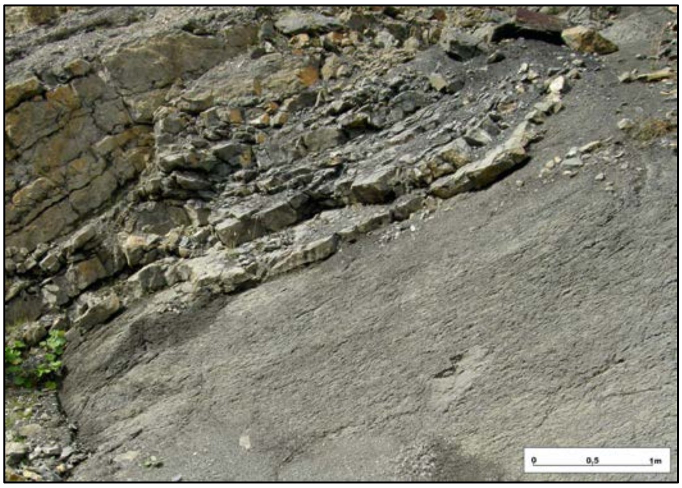
The locality is important as it exposes a section through the complete Lawmuir Formation, marked by the Hurlet Limestone at its base and by the McDonald Limestone at its top. The formation is composed of a sequence of mudstone, siltstone, ironstone, sandstone, and marine limestone. The limestones and mudstones contain abundant fossils; in particular, Giganto productids (simple large productids brachiopods) are common within the Hurlet Limestone, whilst the mudstones contain well-preserved in-situ fragments of crinoids and brachiopods including Spirifer. Of lesser importance at this particular locality, there are also a number of brittle fault-related structures (fractures and slickenlines) cutting the mudstones and limestones. The faults are mineralised at this location, which is not often seen across the Spireslack void.

<u>Access</u>

The site affords good hands on access to study the sedimentary rocks, and would be suitable as a teaching locality with some cleaning of surfaces – however, there are a number of potential loose blocks above the face that would need securing before this became a teaching locality. The mudstones are fragile and eroding, making access to some faces difficult. The overall section is best viewed from a distance 3 - 4 m from the break in slope. A viewing platform here to appreciate the section is recommended.

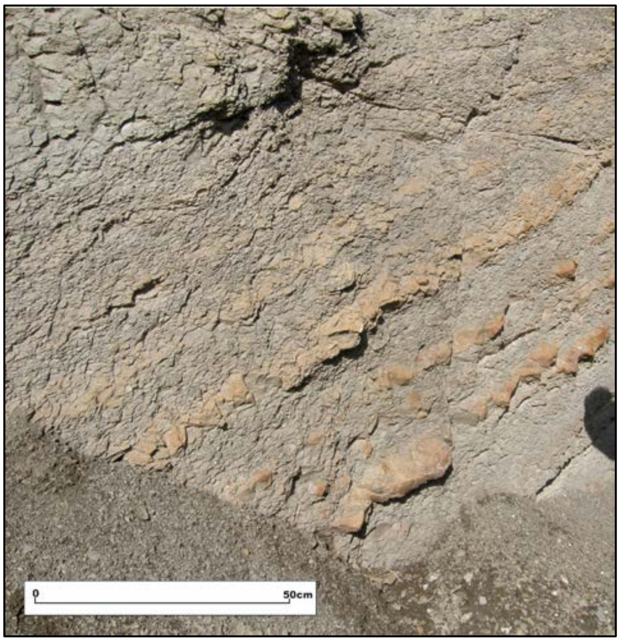
Site Photographs

Spireslack_1 P1: Section showing McDonald Limestones to the left of the rucksack and the Hurlet Limestone to the right of the rucksack. © BGS, NERC.



Spireslack_1 P2: 3 m thick section of the brown-yellow bedded Hurlet Limestone overlying dark-grey fossiliferous mudstone (Lawmuir Formation). © BGS, NERC.

Spireslack_1 P3: Crinoid columns and brachiopods seen within mudstone below the Hurlet Limestone, (Lawmuir Formation). © BGS, NERC.



Spireslack_1 P4: Ironstone bands within the mudstones (Lawmuir Formation). © BGS, NERC.

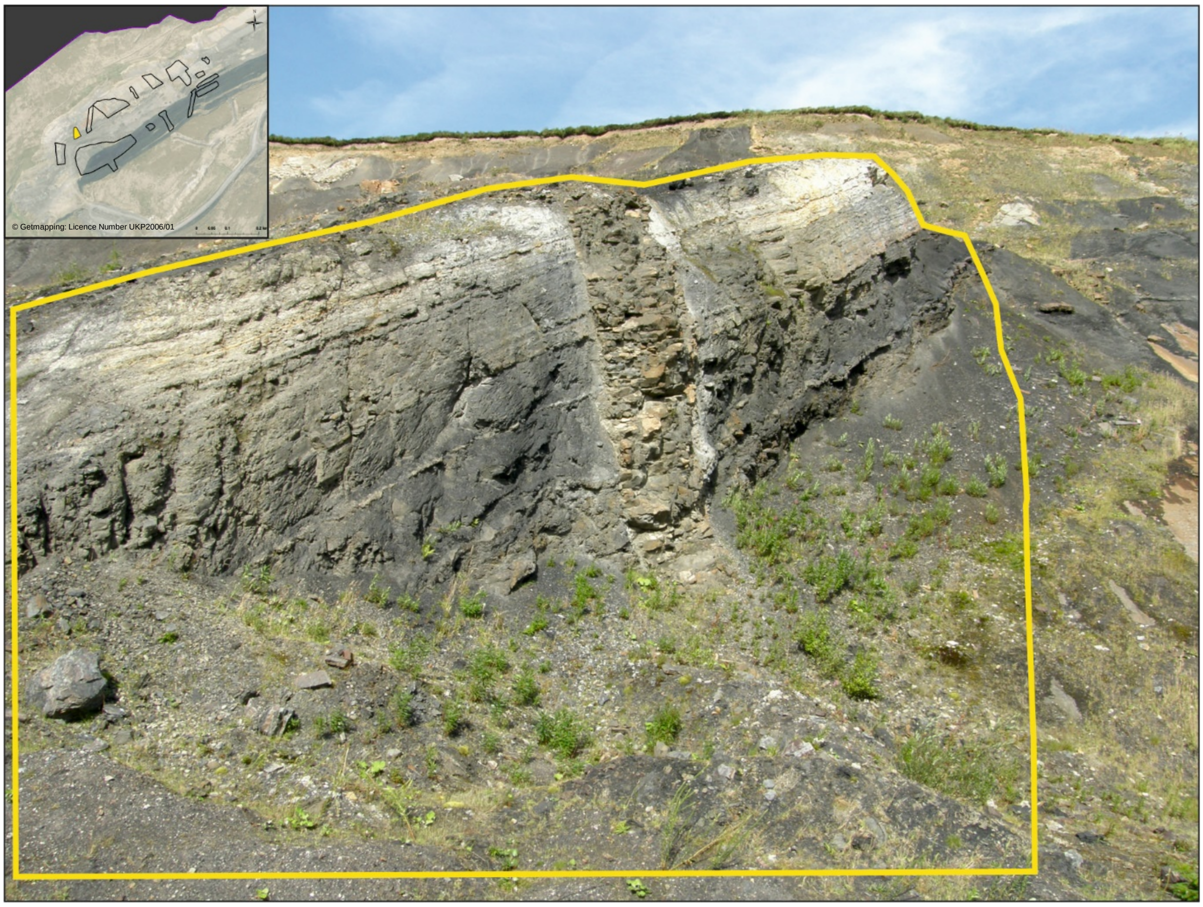
Spireslack Locality 2: Palaeogene dyke intruding mudstones and ironstones	**NGR**: [274539 630416]

Key categories of interest	Rarity	Quality
1. Igneous rocks	★★★★	★★★★★
2. 3D visualisation	★★★★	★★★★
3. Stratigraphy	★★★	★★★★
4. Sedimentary rocks	★	★★
5. Structural geology	★★	★★

Access: Good access to base of exposure, easily accessible from roadway.
Current safety: Potential loose overhanging blocks above section.
Measures to enhance site: Viewing platform 5 m away, level spoil at base of section.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of Locality 2. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site. Photo looking north.

Site Description

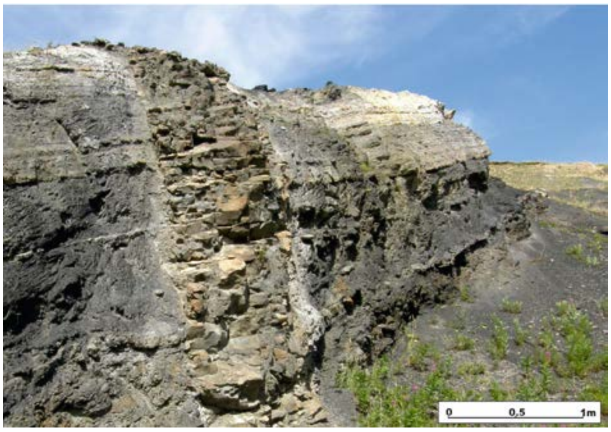
Geology

An exceptionally well exposed Palaeogene quartz dolerite dyke intrudes the Limestone Coal Formation at this locality. The intrusive contact with the Limestone Coal Formation displays chilled margins, mineralisation and alteration of the surrounding mudstone units. The Limestone Coal Formation is also slightly offset across the dyke. Movement along fracture planes within the mudstone, associated with a nearby fault, has caused polishing of the mudstone. There are also small thrust faults developed within the sequence, highlighted by the stronger ironstone layers. The same dyke is also exposed in the scarp (inaccessible), and whilst the dyke itself has been dug out of the void during coal extraction, this location provides an important reference point for providing an indication of orientation, scale and 3D sense of the intrusion. See also Locality 14 for description of geology surrounding dyke exposure in the scarp.

Access and enhancement suggestions

The dyke is easily accessible on foot from roadways and would provide hands on access as a teaching locality. However, there are loose blocks in the face and the mudstone is liable to weathering – this would require inspection by qualified personnel if the site is to be used for close inspection. Alternatively a viewing platform 5 m from the base of the section would also provide a good viewpoint.

Site Photographs



Spireslack_2 P1: Palaeogene dyke intruding mudstones and siltstones of the Limestone Coal Formation. © BGS, NERC.

Spireslack_2 P2: The same dyke exposed in the main scarp, cutting the Limestone Coal Formation. Note, where the dyke is in contact with coal it is altered to white trap: the result of volatiles released during intrusion of magma into carbonaceous rocks (e.g. coals, mudstones). © BGS, NERC.

Spireslack_2 P3 & P4: The left image shows development of small thrust faults within the Limestone Coal Formation, highlighted by ironstone layers. The stronger ironstone layer is buckled and faulted – the same structures are not observed in the mudstone as it is a weaker unit, and deforms along multiple internal fractures. These internal fractures display heavily polished surfaces, evidence of the rocks on either side moving past each other (see right image). © BGS, NERC.

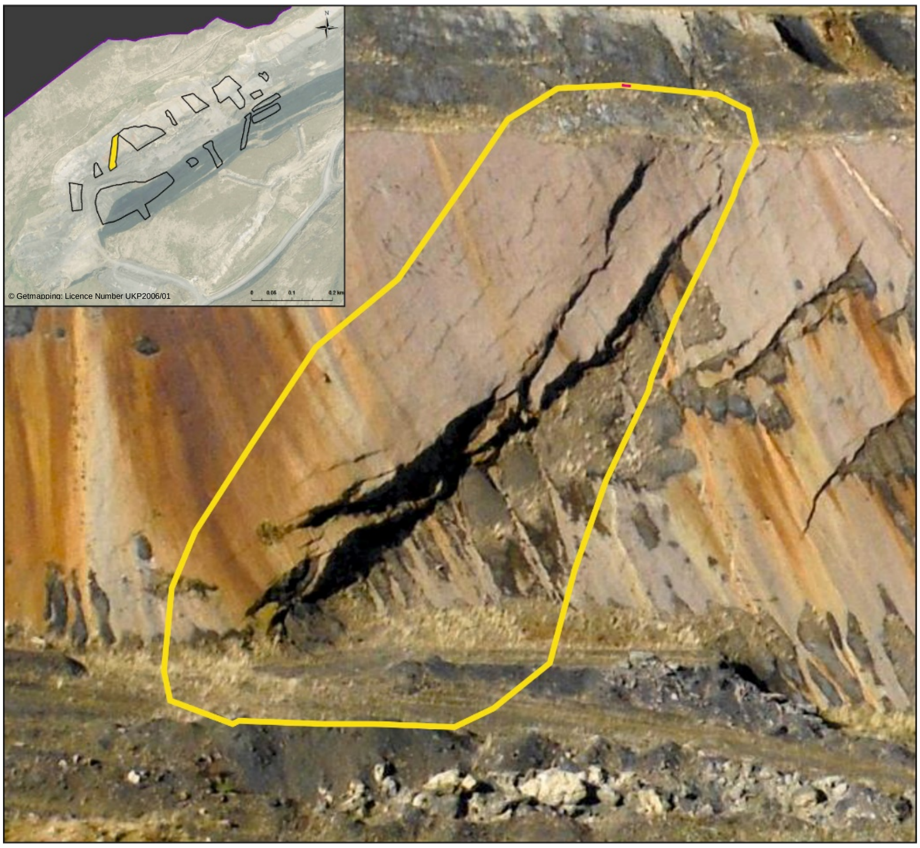
Spireslack Locality 3: Fault zone with relay ramps in McDonald Limestone	**NGR**: [274579 630434]

Key categories of interest	Rarity	Quality
1. Structural geology	★★★★	★★★★★
2. Mineralisation	★★★★	★★★★★
3. Sedimentary rocks	★	★★★★★
4. Palaeontology	★★	★★★★★

Access: Good access, easily accessible from roadway.
Current safety: Little evidence of recent falling blocks observed on limestone pavement, uneven surfaces.
Measures to enhance site: Clean up loose scree and level surface around the site.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of Locality 3. Site boundary includes key rock exposures, a buffer zone around the exposures to place the fault in context, to include the damage zone of the fault in the limestone pavement and to allow room for viewpoints at the base of the site.

Site Description

Geology

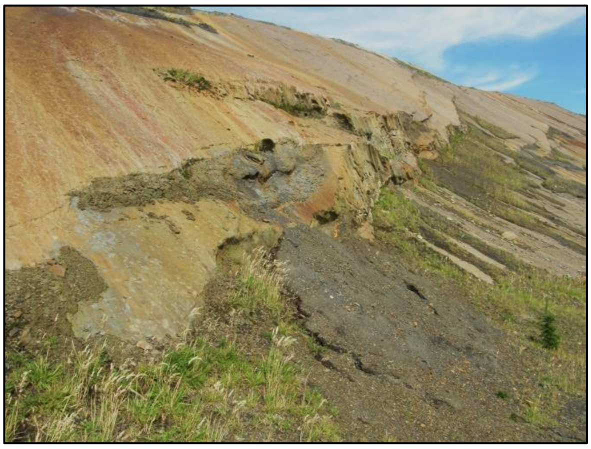
An exceptionally well exposed fault zone cuts the McDonald Limestone pavement at this locality, offsetting it sinistrally by around 5 m. The fault zone displays textbook examples of relay ramp structures (precursors to fault linkage and important for fluid flow migration and understanding fault growth), and highlights that faults are not simple planar structures as is commonly assumed. The fault zone comprises many curvi-linear fault planes with excellent preservation. Each fault plane, where it cuts limestone, also contains spectacular sub-horizontal slickenlines, and the fault planes themselves are extensively mineralised by multiple generations of calcite. Other faults within Spireslack are not typically mineralised. Where the fault cuts mudstones underlying limestone, slickenlines are not preserved and the mudstone is shattered.

This is also a good locality to study the McDonald Limestone pavement's natural joint sets and palaeontology. At this locality trilobite fossils have been found (rare across the Spireslack site) and trace fossils that litter the limestone pavement are well exposed here.

Access and enhancement suggestions

The fault zone is easily accessible on foot from existing roadways and would provide hands on access as a teaching locality. Textbook examples of classic fault structures exhumed in 3 dimensions are relatively rare nationally, and particularly on this scale. These examples are of the highest quality. A viewing platform at the base of the structure would provide an excellent vista along the trace of the fault.

Site Photographs



Spireslack_3 P1: The fault zone and associated relay ramp structures are spectacularly exposed, highlighting important fault architecture components such as displacement length profiles (important for predicting how long fault traces are and where their maximum displacement is), relay ramp evolution (geometries of these are important for modelling fluid migration across rock volumes) and damage zone features associated with a 5 m displacement fault. Looking up-slope, toward the north-east. © BGS, NERC

Spireslack_3 P2: Detail of mineralised slip surface along fault plane. Calcite veining is extensive across the fault planes, and has also been polished by fault movement (evidenced by development of slickenlines). Multiple generations of calcite are found at the site suggesting multiple phases of faulting.© BGS, NERC

Photo Spireslack_3 P3: Trilobite (*Paladin* sp.) seen on the McDonald Limestone pavement but no longer present due to erosion of the flaky surface.© BGS, NERC

Spireslack Locality 4 (and 4b): Palaeogene dyke network exposed on McDonald Limestone	**NGR**: [274631 630471] – [274698 630512]

Key categories of interest	Rarity	Quality
1. Igneous rocks	★★★★★	★★★★★
2. 3D visualisation	★★★★	★★★★
3. Structural geology	★★	★★
4. Mineralisation	★★	★★

Access: Good access to base of exposure, easily accessible from roadway.

Current safety: Little evidence of recent falling blocks observed on limestone pavement, uneven surfaces, loose scree on limestone pavement. Occasional falling loose scree noted on main scarp exposure.

Measures to enhance site: Clean up loose scree overlying dyke on limestone pavement, and level surface around the site as viewing platform.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of Locality 4 and 4b (north and south wall respectively). Site boundary includes key rock exposures, immediate access to site and potential for viewpoints to the site at the base of the limestone pavement. Photo on the left looking to the north, photo on right taken looking south toward scarp.

Site Description

Geology

An exceptionally well exposed Palaeogene quartz dolerite dyke network is seen intruding the McDonald Limestone at this location. The same dykes on the limestone pavement are also exposed in the scarp, where they appear as isolated strands (i.e. not spatially linked to one another). However, the exposure on the McDonald Limestone proves the apparently individual dykes from the scarp merge together in 3D space. This locality provides a very good opportunity to study the 3D geometries of intrusive bodies throughout layered strata on a large scale, as well as the mechanical effect igneous intrusions have on the strata, e.g. the McDonald Limestone is buckled and faulted at the margins of the dyke. As well as the1 m thick dykes, there are also thinner (c.40 cm) dykes within the locality boundary which display baking of adjacent strata, alteration of the dolerite to white trap, and mineralised surfaces. These smaller dykes are also visible on the scarp. In addition to the 3D visualisation interest of observing the dykes on the limestone pavement and then on the scarp, the scarp exposure also shows areas where the dyke has been altered to white trap, a process related to intrusion of hot magma into organic rich rocks.

<u>Access and enhancement suggestions</u>

This section is easily accessible on foot from roadways. Access could be improved by flattening the area in front of the dyke to provide a viewing platform to appreciate the 3D geometry of the dyke network. For the exposure in the scarp, a level platform 5 m from the base would provide an appropriate viewing area for the dyke.

Site Photographs

Spireslack_4 P1: Two approximately 1 m thick quartz dolerite dykes merge near the top of the limestone pavement. The leftmost dyke has a linear trend, whereas the rightmost dyke curves to merge with it in the centre of the photograph. The intruding dolerite has locally distorted the limestone and baked it at its contact. © BGS, NERC.

Spireslack_4 P2: Limestone which has been baked at the dyke margin. Calcite mineralisation associated with the intrusion runs parallel to the dyke's contact with the limestone. © BGS, NERC.

Spireslack_4 P3: Much of the lower part of the dyke in the scarp is covered in spoil and vegetation. Where the dyke cuts organic rich layers (i.e. coal or mudstone) the dyke has been altered to white trap. © BGS, NERC.

Spireslack Locality 5: Shark spine fossil in McDonald Limestone Pavement	**NGR**: [274730 630539]

Key categories of interest	Rarity	Quality
1. Palaeontology	★★★★★	★★★★★
2. Sedimentary rocks	★	★★★★★
3. Economic geology	★★★★★	★★★★★

Access: Good access to base of exposure, easily accessible from roadway.
Current safety: Little evidence of recent falling blocks observed on limestone pavement, uneven surfaces
Measures to enhance site: Protect area to preserve shark spine and level surface around the base of the site to allow easier access.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of locality 5. Site boundary includes key rock exposures (from the shark spine at the base of the pavement to the crescent shaped digger marks near the top), immediate access to site and viewpoints to the site. Photo taken from scarp looking south.

Site Description

Geology

The McDonald Limestone pavement, comprising the entirety of the northern limit of the main Spireslack void, is rich in fossils allowing an insight into the fauna that existed during Carboniferous times. Fossilised shell fragments and trace fossils are the most common, with trilobites also known from the site (see locality 3). At this locality, a beautifully preserved 5 cm long shark spine is exposed at the base of the pavement – the only one recognised within the Spireslack site to date. This locality is ideal for palaeontological studies as well as providing hands on access to limestone. Higher up the limestone pavement are two crescent shape marks – these are not geological features, but grooves left by the giant machinery which would have worked the coal from the pit during mining activity.

Access and enhancement suggestions

The shark spine should be protected from erosion – the limestone pavement has a flaky surface and over time the shark spine may erode. Flattening the area of ground in front of the pavement to allow easier access and viewing is also recommended. A fossil hunt trail could be set up to explore the fauna that lived in Spireslack during the Carboniferous – this would be a key site for such a trail.

Site Photographs

Spireslack_5 P1: Fossilised shark spine preserved in the McDonald Limestone. This shows that during the Carboniferous in Spireslack, sharks were swimming in shallow, warm seas when Scotland was close to the equator. © BGS, NERC.

Spireslack_5 P2: Crescent shaped 2 m wide markings (outlined in dashed green circle) are found on the limestone surface, created by machinery during coal extraction. © BGS, NERC.

Spireslack_5 P3: Trace fossils litter the surface of the McDonald Limestone pavement. The dark branching structures in the photo are the fossilised traces of creatures which would have travelled the seabed surface of the pre-lithified limestone for food. These tracks can be up to 10 cm long – there are also mm-long tracks preserved on this surface. © BGS, NERC

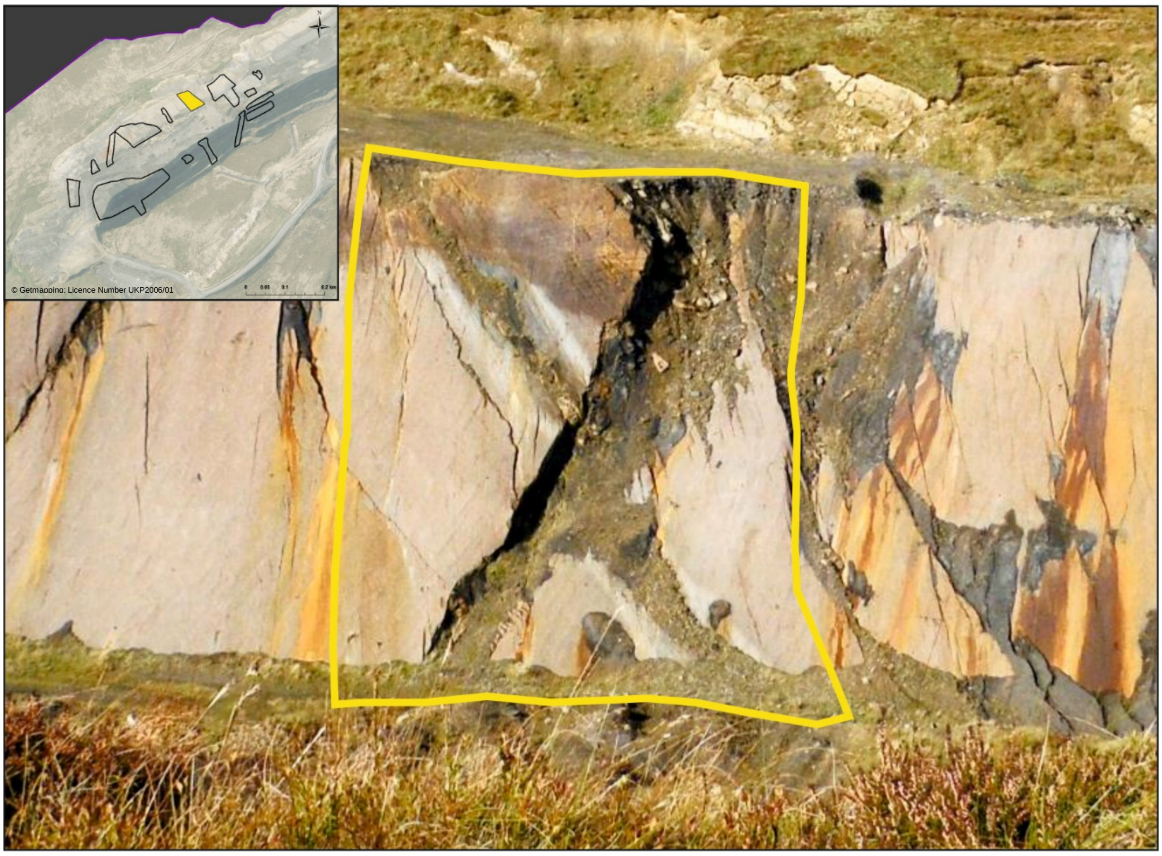
Spireslack Locality 6: Fault cut by dyke	**NGR**: [274784 630568]

Key categories of interest	Rarity	Quality
1. Structural geology	★★★	★★★★★
2. Igneous rocks	★★★★	★★★★
3. 3D visualisation	★★★	★★★★

Access: Good access to base of exposure, easily accessible from roadway.
Current safety: Little evidence of recent falling blocks observed on limestone pavement, uneven surfaces
Measures to enhance site: Flatten area at base of exposure as viewing area

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of Locality 6. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site. Photo taken from scarp, looking north.

Site Description

Geology

At this locality a fault displaces the McDonald Limestone pavement down c. 2 m to the east. The fault displays well preserved slickenlines along the fault plane, indicating a sinistral sense of movement. A 1 m wide dolerite dyke cuts through the fault plane, thus proving the dykes that intrude the strata across Spireslack were emplaced after faulting had ceased. This is vital evidence for deciphering the geological history of the area. The same fault is observed on the scarp, providing a 3D perspective for fault networks across Spireslack.

Access and enhancement suggestions

The fault is easily accessible from existing roadways and the face is clean. A post or board indicating the direction of the equivalent fault in the scarp would aid in 3D visualisation appreciation.

Site Photographs

Spireslack_6 P1: Fault plane with well-preserved slickenlines and smearing of limestone layers across fault plane. The dyke cross cutting the fault is indicated with an arrow. © BGS, NERC.

Spireslack_6 P2: The same fault observed in the scarp, where it is seen in section cutting mudstones, coal and sandstones. © BGS, NERC. This fault is best observed from the northern limestone pavement as its features are obscured up close.

Spireslack Locality 7 (and 7b): Complex fault zone in McDonald Limestone	**NGR**: [274845 630590] – [274895 630623]

Key categories of interest	Rarity	Quality
1. Structural geology	★★★★★	★★★★★
2. 3D visualisation	★★★	★★★★

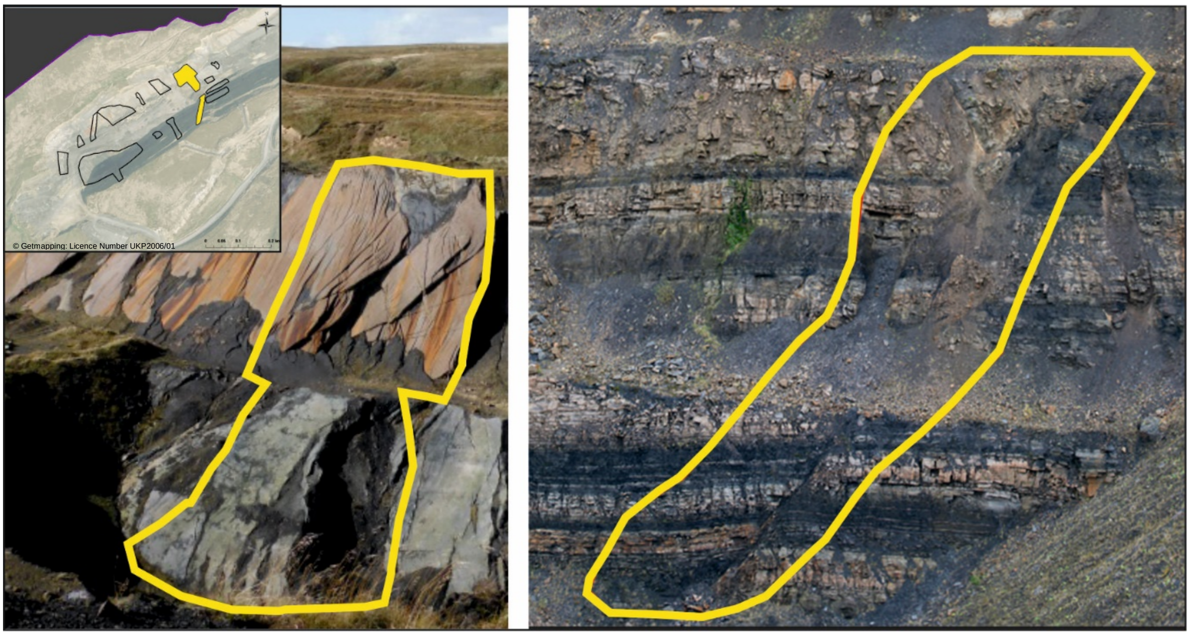
Access: Good access to base of exposure, easily accessible from roadway.

Current safety: Potential for falling blocks/scree from limestone pavement, sharp drop behind access

Measures to enhance site: Viewing platform away from steep drop and large rocks; barrier between platform and steep drops.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of Locality 7 and 7b (north and south wall respectively). Site boundary includes key rock exposures, immediate access to site and viewpoints to the site. Left photo taken from scarp looking to the north, and right hand photo taken looking to the equivalent fault on the south of the void.

Site Description

Geology

Whilst there are many small faults intersecting the McDonald Limestone pavement, none are quite as spectacular as the structures associated with the > 5 m displacement fault at this locality. The west-most wall of the fault in the limestone is heavily fractured and faulted, containing a complex network of conjugate and linked small-displacement faults. Relay ramp structures are also well developed. As in Locality 3, structures like these are rare but are critical to study in order to further the understanding fault growth and evolution. Fault rocks (primarily limestone fault-breccias) are observed along the planes of some of the larger displacement faults. Thin dykes also cut the limestone pavement. The main fault also displaces the mechanically weaker seatearth in the lower half of the void, where the west most wall of the fault has a markedly different faulted signature than that of the mechanically stronger limestone. This is important to highlight how faulting affects rocks with differing mechanical strengths. The fault is visible in section view in the main scarp, where it also displaces one of the Palaeogene dykes. Together the localities on the north and south of the void contribute to a 3D understanding of fault networks cutting coal-bearing sequences.

Access and enhancement suggestions

This locality is accessible from existing roadways and there is sufficient space at the base of the pavement to stand safely to view the structures. The seatearth in the lower part of the void is also accessible, although the pond in the lower void is liable to flood and may impede access at times. A flood barrier could be constructed to avoid this. Barriers at the top of the seatearth horizon would improve safety for viewing the structures in the limestone pavement.

Site Photographs

Spireslack_7 P1: Spectacular fault structures, including relay ramps, limestone lenses and small faults have formed in response to faulting of the McDonald Limestone pavement . © BGS, NERC.

Spireslack_7 P2: The fault is also seen in the scarp of the void – however, the damage associated with the west side wall of the fault is not as obvious in this section view as it is on the limestone pavement. The fault also displaces a Palaeogene dyke. © BGS, NERC.

Spireslack_7 P3: Fault breccia, formed from fracturing and rotation of the stiff McDonald Limestone along the main fault plane. Fault rocks can give an indication of how intense the faulting was and how often the sequence has been faulted. © BGS, NERC.

Spireslack_7 P5: Foreground shows the faulting style of the seatearth, sitting stratigraphically above the McDonald Limestone. The main fault displacing the units is to the right of the photos, but the intense deformation recorded in the west wall of the fault by the limestone is less obvious in the seatearth – a result of the differing mechanical strengths of the units faulted. © BGS, NERC.

Spireslack Locality 8: Seatearth with stigmaria and tree casts	**NGR**: [274933 630610]

Key categories of interest	Rarity	Quality
1. Palaeontology	★★★★★	★★★★★
2. Sedimentary rocks	★★★★	★★★★

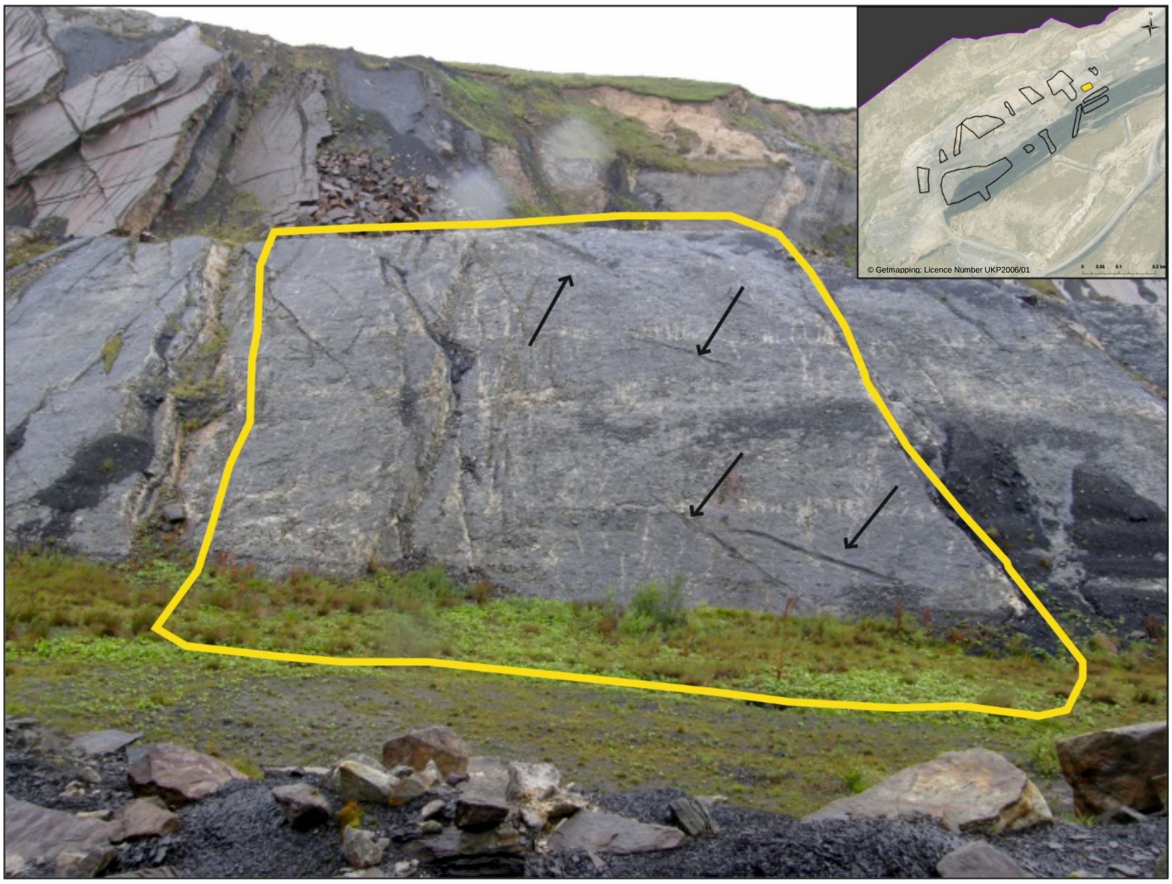
Access: Good access to exposure following emplacement of new roadway (September 2015).

Current safety: The floor of the pit near the base of the seatearth is liable to flooding when the groundwater table is high, and there are voids opening up, possibly related to shallow coal workings.

Measures to enhance site: Provide stable ground and flood prevention methods to ensure continued access to base of seatearth exposure; ideally 2 – 3 m zone.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of Locality 8. Site boundary includes key rock exposures, immediate access to site and suggested viewpoints to the site. Tree casts are highlighted by arrows.

Site Description

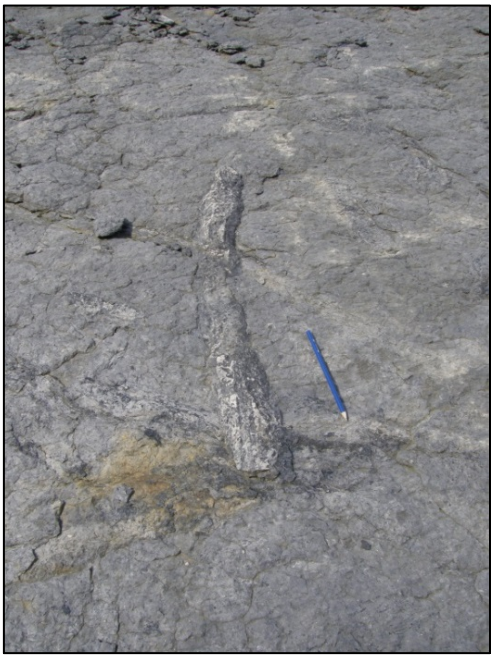
Geology

The seatearth horizon is the lithified equivalent of the soils that the McDonald Coal organic material rested on before turning into rock (i.e. the remains of a swampy forest). The seatearth is full of fossilised stigmaria (tree roots), tree trunk casts (possibly *Lepidodendron* sp.) and other plant material, some in situ. It is rare to see these in original position and across such a wide area, as seatearth is typically a fast eroding unit due to a higher content of clay minerals. At the locality there are numerous, excellently preserved examples of in situ tree fossils, including one c. 5 m long tree trunk cast. The seatearth and fossilised trees indicate deposition in estuarine conditions with sea level receding and fresh water marshes developing periodically.

Access and enhancement suggestions

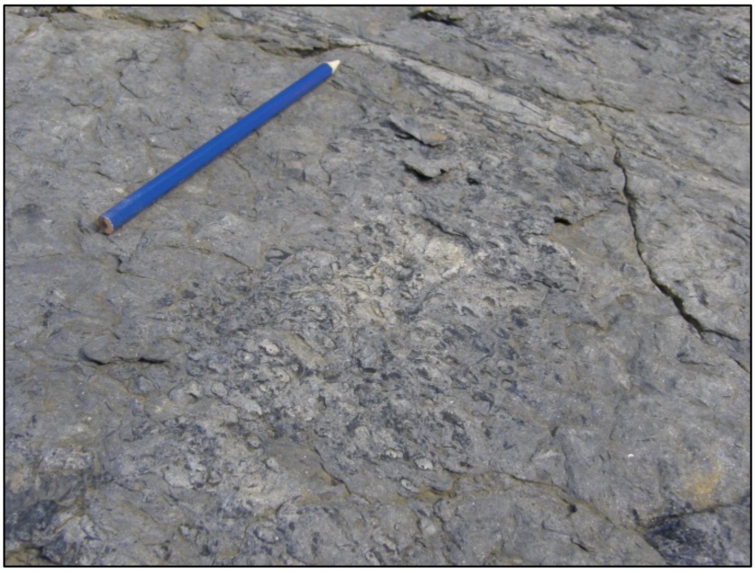
The seatearth surface is eroding rapidly – this in turn is exposing tree fossils from their in situ positions. Parts of the seatearth surface should be treated and protected to ensure tree fossils remain in situ (i.e. remain in the place as they were deposited during the Carboniferous). This would also be an ideal teaching locality.

Site Photographs



Spireslack_8 P1: Fossilised roots (stigmaria) of *Lepidodendron* sp., a tree-sized fern, are abundant within the McDonald seatearth. © BGS, NERC.

Spireslack_8 P2: *Lepidodendron* sp. tree cast within McDonald seatearth. Note erosive nature of seatearth in lower left – this is comprised mostly of stigmaria root fossils. © BGS, NERC.



Spireslack_8 P3: Detail of stigmaria root within McDonald seatearth. The circular scars on the root surface are the preserved remains of smaller rootlets (stigmata) which were once attached and arranged radially around the stigmaria. © BGS, NERC.

Spireslack Locality 9: Johnstone Shell Bed	**NGR**: [274950 630648]

Key categories of interest	**Rarity**	**Quality**
1. Palaeontology	★★★★★	★★★★
2. Stratigraphy	★★★★★	★★★
3. Mineralisation	★★★★★	★★★★★

Access: Good access from lower void.
Current safety: Uneven underfoot and steep but firm in places.
Measures to enhance site: Create a dedicated path to site, clean up loose scree around site.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of Locality 9. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site. Photo looking toward the west-south-west in lower part of void.

Site Description

Geology

The Johnstone Shell Bed, a marine band and important regional stratigraphic marker across the Midland Valley, is exposed at this locality in a small water-washed gully. Marine bands such as these represent a time when Carboniferous Scotland was under the sea, a change from the dominant estuarine and deltaic conditions that typically form the Limestone Coal Formation. As such, these flooding events, where marine life flourished across wide geographical areas, can be recorded and correlated across Scotland. The Johnstone Shell Bed is therefore an important regional stratigraphic horizon across the Midland Valley, containing fossil evidence for the fauna which flourished during marine incursions in Scotland. At the locality, a 50 cm wide exposure of the fossiliferous shell bed is revealed by surface water cutting shaley scree. In the neighbouring seatearth, adjacent to the shell bed, are remnants of the McDonald Coal. Fractures within the coal have been mineralised by ankerite, an orangey brown earthy mineral not found preserved in situ elsewhere in Spireslack. Ankerite is a mineral often associated with coals.

Access and enhancement suggestions

The shell bed is very fragile and friable, although the current cover of shaley scree is protecting it. Measures to prevent erosion of the bed, and cover by scree, should be put in place as this is an important regional stratigraphic marker.

Site Photographs

Spireslack_9 P1: Ankerite mineralisation within coal cleats (fractures within coal) and fault zones cutting coal. Ankerite is a carbonate mineral containing ferrous iron, which turns the mineral brown as a result of weathering. It is thought to be a product of late-stage diagenesis (Younger, 2004). © BGS, NERC

Spireslack_9 P2: Johnstone Shell Bed exposed in a water-washed gully. Note fissile nature of beds which make it an easily erodible unit. © BGS, NERC.

Spireslack_9 P3: Detail of the Johnstone Shell Bed, a marine band containing abundant calcareous brachiopods. © BGS, NERC.

Spireslack Locality 10: View of major fault | **NGR**: [275188 630710]

Key categories of interest	Rarity	Quality
1. Structural geology	★★★★	★★★★
2. Stratigraphy	★★★	★★★

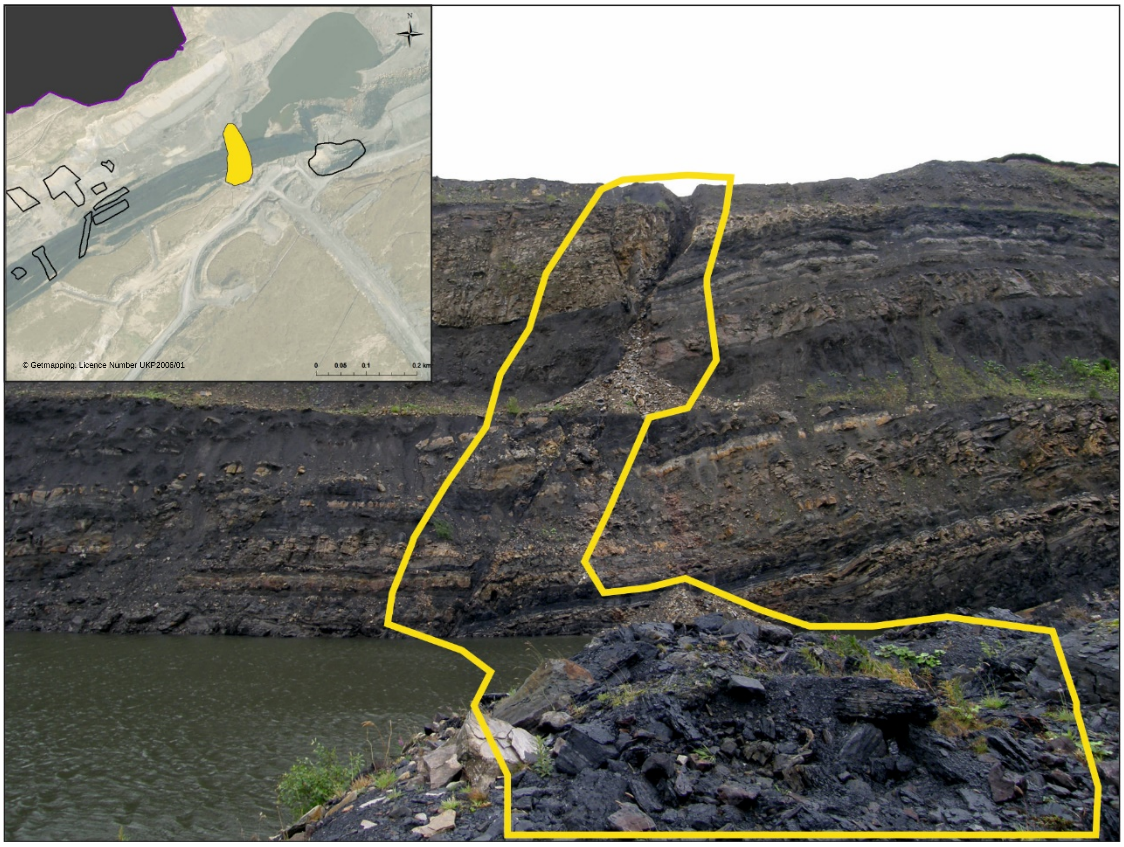
Access: Good access to view the fault from base of void. Hands-on access is not possible.

Current safety: Viewing area would be safe but there is clear evidence of loose rock falling from higher in the fault zone, forming an active debris cone: therefore close approach to this location is dangerous. Deep pond between potential viewing platform and fault.

Measures to enhance site: Flatten out the ground in front of the site as viewing platform.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of Locality 10. Site boundary includes key rock exposures, immediate access to site and potential viewpoints to the site (foreground in right of photo overview). Note active debris cone accumulating half way up main scarp. Photo looking to the south.

Site Description

<u>Geology</u>

At this locality, within the scarp, a major fault displacing the Limestone Coal Formation is observed. The oblique-slip fault throws down the rock sequence in an apparent normal sense to the east, as well as displacing the strata in a northerly direction. This effect is observed in the McDonald Limestone pavement on the north wall of the void, where the footwall of the fault is observed but the equivalent hangingwall limestone is buried beneath quarry spoil. Nevertheless, the locality impressively shows the large scale at which faults can displace rocks within the subsurface.

Access and enhancement suggestions

The fault itself is inaccessible due to the danger of rock fall on the scarp, and also the presence of the deep pond in front of it. This site in any case is better viewed from a distance to appreciate the displacement of the rocks on either side of the fault. Some of the larger spoil piles on the north-west side of the pond could be levelled to provide a viewing platform.

Site Photographs

Spireslack_10 P1: Fault in the south wall, displacing rocks in an apparent normal sense down to the east (left of the image), but also to the north in an oblique sinistral fashion. The weaker fault rocks have been eroded along the fault plane, leaving a cleft marking the position of the fault. Sandstone tends to fracture when faulted – the fractured sandstone has washed out of the fault plane to form a localised debris cone half way up the scarp. Photo facing south. © BGS, NERC.

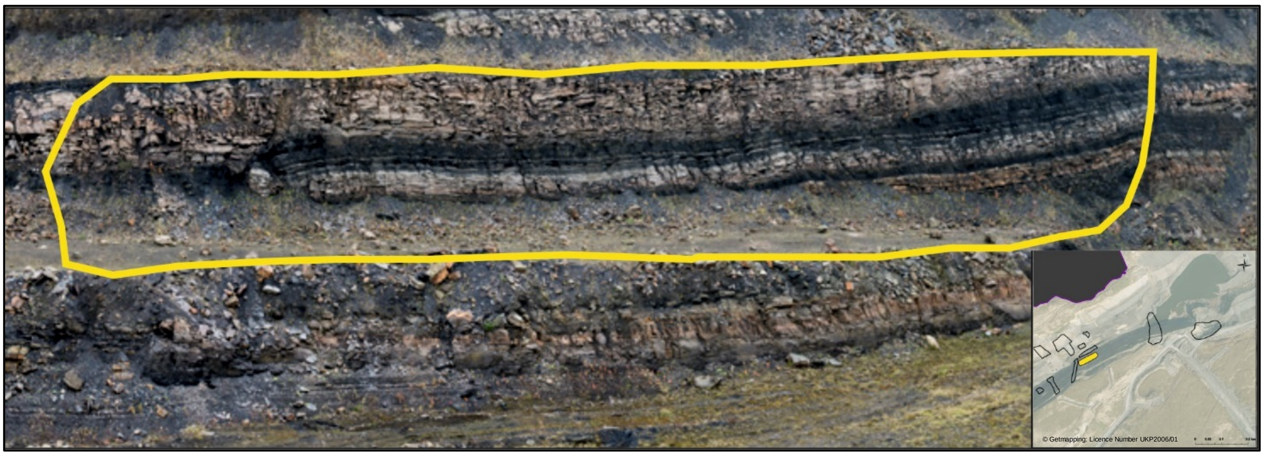
Spireslack Locality 11: Section through old mine workings with in-situ pit prop	**NGR**: [274976 630578] – [274923 630554]

Key categories of interest	Rarity	Quality
1. Economic geology	★★★★★	★★★★★
2. Stratigraphy	★★★	★★★★
3. Sedimentary rocks	★★★	★★★★

Access: Good access to base of exposure.
Current safety: Loose material noted spalling off main scarp, potential loose overhanging blocks above section.
Measures to enhance site: Create dedicated viewing area for platform.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of Locality 11. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site. View looking south onto scarp, at western edge of lower void.

Site Description

Geology

The key interest of this locality is a section through an earlier generation of coal extraction at Spireslack. The earlier 19th/20th century underground mine workings extracted coal from the Muirkirk Nine Foot coal, a regionally extensive coal seam. At the eastern edge of this locality's extent, adjacent to a minor 1.2 m displacement fault, the coal maintains its original (unmined) thickness of c.3 m. However, where mining commenced, the layer which originally contained the coal thins to a maximum of 1.5 m thick and the space that was originally occupied by coal is filled with packed mine waste (representing a collapsed room or short wall working). The sandstone overlying the mine waste is warped downward and fractured, representing collapse of the overlying strata into the mined void. An in situ, fallen pit prop is preserved within the base of mine waste – these wooden pit props would have held up the roof of the mines whilst coal was being extracted. In addition to the economic and stratigraphic geological interest here, blocks of sandstone, mudstone, coal and ironstone nodules are littered across the floor of the void in front of the scarp providing ample hands on opportunities to study the inaccessible rocks on the scarp.

Access and enhancement suggestions

There is good access to view the collapsed mine workings and pit props. Whilst providing a good viewing platform for the mine workings, this also provides a good platform to look to the north to view the tree casts in the McDonald seatearth (described in locality 8).

Site Photographs

Spireslack_11 P1: Section with the Limestone Coal Formation in the scarp at Spireslack. The dark band is the Muirkirk Nine Foot Coal. The left hand side of the image shows the original thickness of this seam, before it narrows and is replaced by packed mine waste. Photograph looking south-west toward main scarp. © BGS, NERC.

Spireslack_11 P2: Wooden pit prop in situ within the coal workings. The wooden props were used to hold up the roof of the workings as the coal was extracted. The prop, sitting above packed mine waste in the photo, has since collapsed due to the overlying weight of rock (sandstone) above. © BGS, NERC.

Spireslack Locality 12: Sedimentary section through Limestone Coal Formation	**NGR**: [274979 630606] – [274930 630564]

Key categories of interest	Rarity	Quality
1. Sedimentary rocks	★★★★	★★★★★
2. Palaeontology	★★★	★★★

Access: Good access to base of exposure, easily accessible from roadway.

Current safety: Uneven surfaces, potentially loose large blocks at top of exposure may pose hazard.

Measures to enhance site: Assess large blocks from above exposure, and assess any remedial measures necessary. Clean surface to enhance sedimentary structures.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of locality 12. Site boundary includes key rock exposures and immediate access to site. Photo looking south toward the scarp, whilst standing at base of lower void.

Site Description

Geology

A rare chance within the Spireslack void for an apparently safe, in situ sedimentary sequence to be examined is the focus of this locality. A 5 m section through part of the Limestone Coal Formation allows hands on access to a coarsening upwards sequence of sandstones, mudstone, siltstones, representing a deltaic environment. The sandstone in the section displays a distinct two tone appearance, a characteristic also observed in a sandstone higher in the sequence – the latter unit is traceable across the length of the scarp, and acts as a key marker bed when following the sequence across faults. The sedimentary rocks contain abundant bioturbation, crinoid fragments and organic remains.

Access and enhancement suggestions

There is good access to the section, but by providing a level base to view the sequence this would improve access, and cleaning the rock face would assist in the understanding of the depositional environment of these sedimentary rocks.

Site Photographs

Spireslack_12 P1: Section of Limestone Coal Formation, showing a 5 metre coarsening upward sequence through mudstones to sandstones. © BGS, NERC.

Spireslack_12 P2: Crinoid fragments are abundant within the sandstone. © BGS, NERC.

Spireslack Locality 13: Cannel Coal	**NGR**: [274777 630440]

Key categories of interest	Rarity	Quality
1. Sedimentary rocks	★★★★★	★★★★

Access: Good access to base of exposure, easily accessible from roadway.

Current safety: Loose material and rocks present a potential hazard.

Measures to enhance site: Viewing platform 5 m from base of scarp with examples of cannel coal to avoid any need to approach the main scarp.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of locality 13. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site.

Site Description

Geology

This locality provides a viewable section of a 30 – 40 cm thick band of cannel coal within the Limestone Coal Formation, set within a thicker, ~75 cm thick section of the Muirkirk Nine Foot Coal. Cannel coal is a bituminous coal more akin to an oil shale than coal, due to its texture and composition. It is rich in oils and burns without smoke, unlike coal. It was accumulated in ponds and shallow lakes in peat forming swamps and bogs under oxygen deficient conditions. Cannel coal breaks with a conchoidal fracture due its very fine-grained nature. This locality provides an opportunity to study a different type of coal to that traditionally mined (i.e. 'sooty' coal) and to place it in stratigraphical context.

Access and enhancement suggestions

Viewing platform away from the base of exposure, to avoid potential of falling blocks from scarp. Accessible blocks of cannel coal could be placed within the viewing platform to allow hands on access without being at base of the scarp.

Site Photographs

Spireslack_13 P1: 20 cm thick band of cannel coal set within the Muirkirk Nine Foot Coal seam. © BGS, NERC.

Spireslack_13 P2: Section of the Limestone Coal Formation showing 2 metre section of coal with the light grey band of cannel coal, with overlying sandstone bed (brown-orange coloured rock). © BGS, NERC.

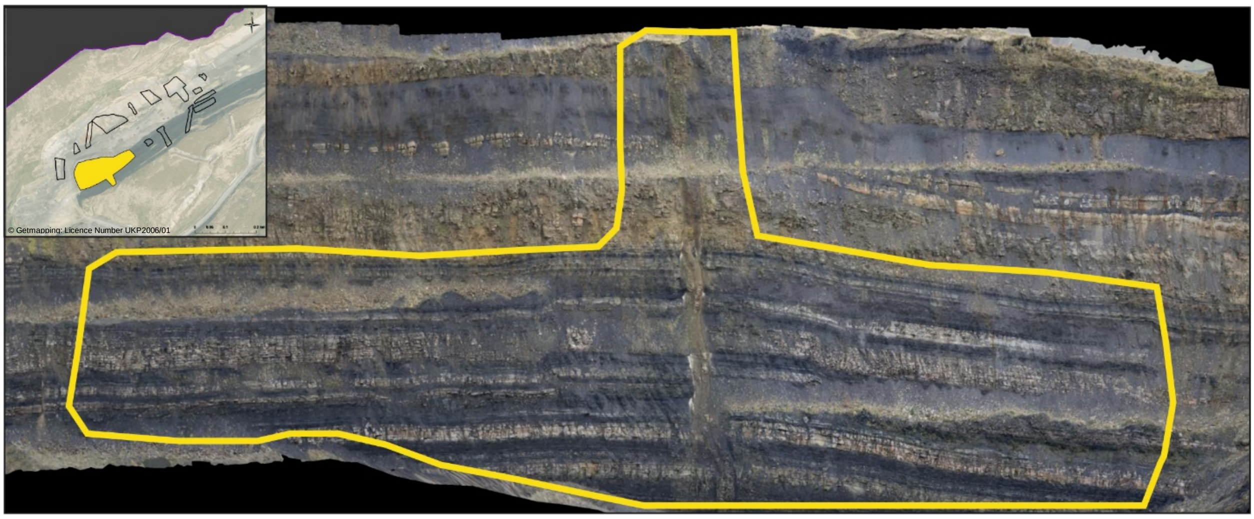
Spireslack Locality 14: Underground mine workings and dyke	**NGR**: [274708 630420 – 274537 630321]

Key categories of interest	Rarity	Quality
1. Economic geology	★★★★	★★★★★
2. 3D visualisation	★★★★★	★★★★★
3. Igneous rocks	★★★	★★★★★

Access: Good access to base of exposure (but danger of rock fall from above), easily accessible from roadway.
Current safety: Potential for falling rocks and potentially unstable surface on scarp. Uneven footing.
Measures to enhance site: Create viewing platform set back from wall to appreciate features.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Overview of locality 14. Site boundary includes key rock exposures, from the underground coal workings to the trace of the dyke from locality 2.

Site Description

Geology

This locality encompasses three key features. The first feature is a section through old underground mine workings, which during operation, extracted the Muirkirk Nine Foot Coal. The old mine workings were left to collapse after extraction and the void which once contained the coal is now filled with packed mine waste – mostly brecciated and poorly sorted coal or other rock fragments. On this wall, the sandstone layer overlying the worked coal horizon is warped downward and fractured, due to settling of the strata above the collapsed mine workings. However, at least 3 pillars within the coal remain visible in the section; these are the rock pillars that were left in place during underground workings to stabilise the mine workings. The second key feature is the exposure of the dyke described in locality no. 2 – see description therein. The third key feature is the view provided at the far west end of this locality. From here the dip of strata within Spireslack in 3D can be appreciated.

Access and enhancement suggestions

Viewing platform to stand back and appreciate the broader internal structure of the mine (remaining pillars, collapsed workings, overlying strata collapse) and linking the dipping strata with the rocks on the scarp.

Site Photographs

Spireslack_14 P1: Eastward edge of old mine workings seen in the south wall. The thick 'pillars' of coal (P) beneath the sandstone bed were used to prop up the roof of the mine workings whilst the coal was extracted from between pillars. © BGS, NERC.

Spireslack_14 P2: Western edges of old mine workings seen in the south wall. The random blocks of sandstone and coal can be seen to the left of the photo, this is infilling the space devoid of coal which has been extracted. The 'pillar' of coal (P) can be seen to the right of these blocks. © BGS, NERC.

Spireslack_14 P3: The middle pillar of this section (P) can be seen in the middle of the photograph. The sandstone bed above the coal, on either side of the pillar, has collapsed after the coal was extracted. © BGS, NERC.

Spireslack_14 P4: Viewing platform, facing west. Good place for visualising the true dip of the strata (wall facing photo) compared to the apparent dip of the strata (seen on the scarp). © BGS, NERC.

Spireslack Locality 15: Calmy Limestone	**NGR**: [75406 30674]

Key categories of interest	Rarity	Quality
1. Stratigraphy	★★★★★	★★★★★
2. Sedimentary rocks	★★★	★★★

Access: Good access to exposure, easily accessible from roadway.

Current safety: Potential for falling blocks at margins of outcrop extent and marshy ground/potential for flooding underfoot at base of exposure.

Measures to enhance site: Create viewing platform and rope off edges of exposure

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of locality 15. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site. Photo taken looking south toward eastern edge of the scarp.

Site Description

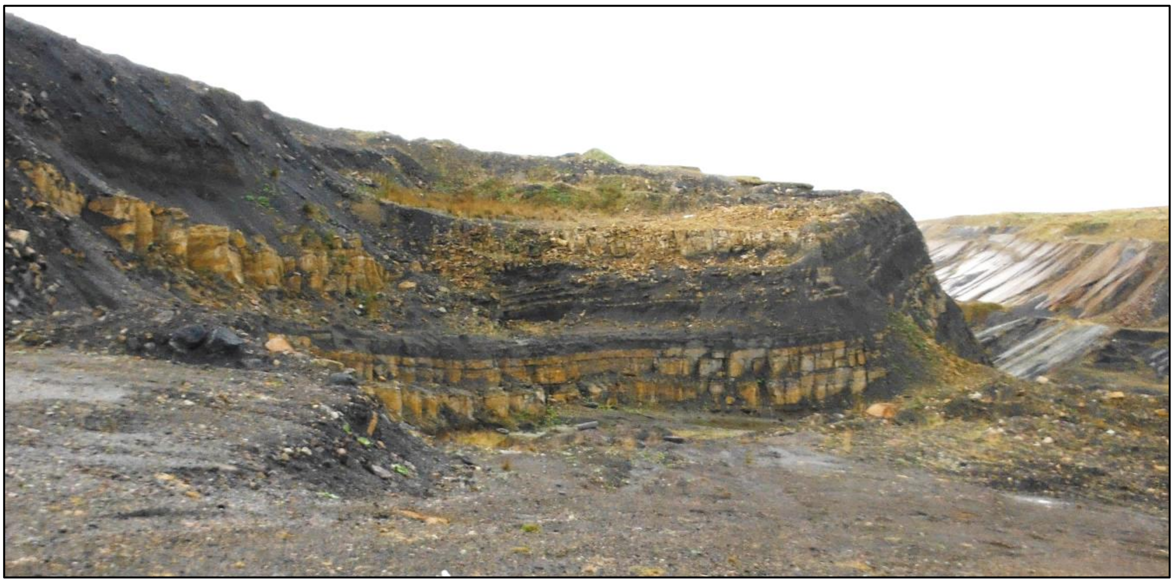
Geology

The Calmy Limestone, belonging to the Upper Limestone Formation, is a laterally persistent marine limestone correlatable across the Central Belt of Scotland. At this locality it is exposed in a 15 m high section at the eastern edge of the Spireslack void. The Calmy Limestone, overlying the Gill Coal at this location, is composed of an interbedded sequence of 1.5 – 2 m thick marine limestones and mudstones. The limestones were deposited in warm, shallow clear waters during maximum flooding events associated with sea level fluctuations at the time. This locality provides an excellent section through the Calmy Limestone sequence, composed of 3 key beds of pale grey, fossil poor, fine-grained, massive limestones. The underlying Gill Coal contains nodules of pyrite throughout, formed in oxygen starved conditions whilst the coal was forming.

Access and enhancement suggestions

Access is good, but potential for loose blocks falling from above prevents any close approach. The base of the area is liable to flooding, therefore flood prevention measures or a raised walkway would allow easier access to the limestones.

Site Photographs



Spireslack_15 P1: The Calmy Limestone beds looking to the west. The Calmy Limestone is composed of three individual thick 'leaves', separated by marine mudstones. The Calmy Limestone here sits above the Gill Coal. © BGS, NERC.

Spireslack_15 P2: Pyrite nodules are present in the upper half of the Gill Coal. The presence of pyrite (iron and sulphur rich) in the Gill Coal indicates oxygen starved conditions at time of deposition, and potentially within a more marine influenced environment (coals produced in fresh water environments contain less pyrite than those formed in marine). © BGS, NERC.

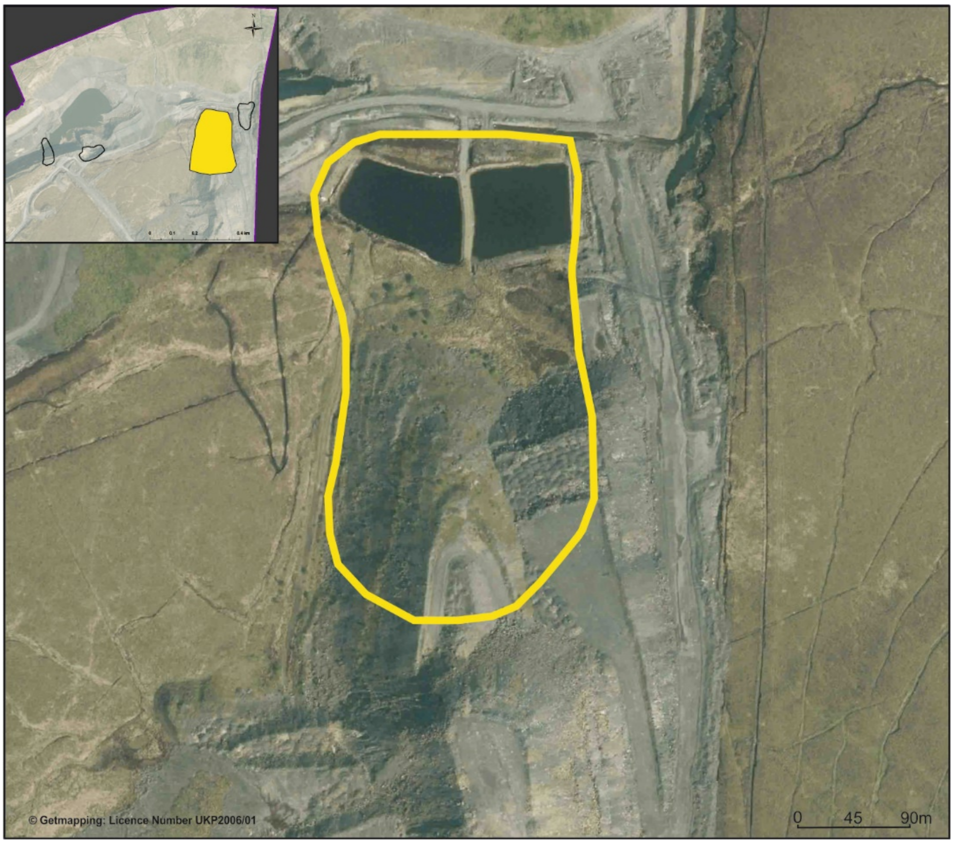
Spireslack Locality 16: Till and peat section | **NGR**: [275957, 630845]

Key categories of interest	Rarity	Quality
1. Quaternary deposits	★★★★	★★★★★
2. Economic geology	★★★	★★★

Access: Good access to section, accessible from roadways.
Current safety: Deep ponds nearby, accessible by road surface.
Measures to enhance site: Clean up sections in entrance to locality to avoid danger of deep ponds.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary



Aerial overview of locality 16. Site boundary includes key geological exposures (in this case peat and till sections within the north of the boundary, and two generations of spoil heap within the south part of the site boundary), immediate access to site and viewpoints to the site.

Site Description

Geology

This locality's primary interest is in its excellently preserved Quaternary deposits within a cutting created during construction of the two man-made fining ponds in the area. Up to 2 m of dark brown peat overlies a sandy glacial till, with the boundary between marked by a conspicuous ~10 cm thick bleached zone. It is thought this bleached zone represents the formation of a podzol (a soil) in the till. This usually forms in cool humid climates where peat develops on top of sandy tills. Where the peat comes into contact with the till, organic compounds in the peat have been washed out by rainfall and combined with aluminium and iron in the layer below. The till layer below has a bleached appearance because it becomes higher in silicon and lower in aluminium and iron – i.e. the main mineral left following podzolisation is quartz. This section preserves the original Quaternary cover that is likely to have covered the site before mining.

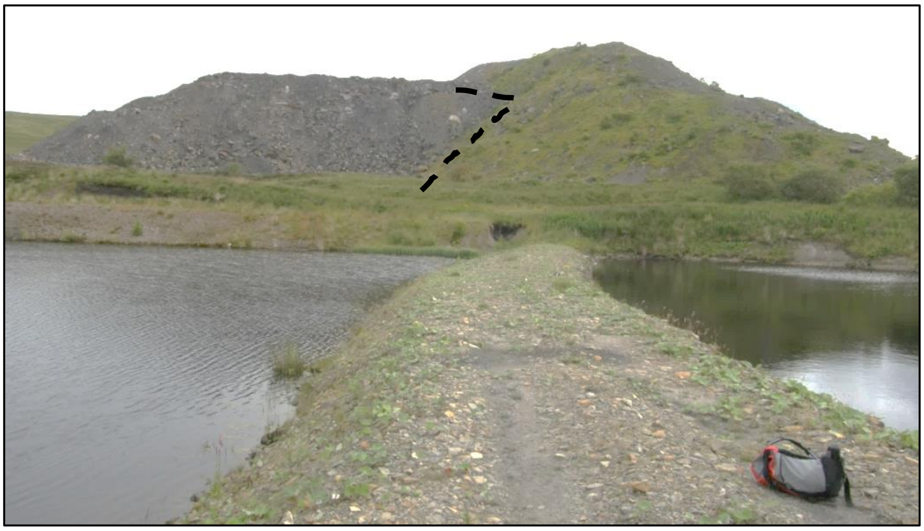
This locality also provides a good viewing area for appreciating two generations of mine waste (related to surface mine operations) to the south, and the natural processes that evolved over each since. The older generation has a cover of sparse vegetation and trees, whilst plant life has just started to grow in the newer generation.

Access and enhancement suggestions

Access is very good as a road has been cut through the peat and till for access to the ponds. Another exposure of peat lying above till can be seen above the Swanshaw Sandstone Formation, see Locality 17 site photos. The site could be enhanced by cutting a new, clean section through the access road before reaching the fining ponds, as hands on access is restricted at the current exposure due to the water level.

Site Photographs

Spireslack_16 P1: Peat overlying 'bleached' till above fining ponds. © BGS, NERC.



Spireslack_16 P2: View south from access pond toward two generations of mining waste. Note the older generation on the right has been naturally colonised by shrubs, vegetation and low growing trees, whereas the newer generation on the left, piled against the older generation, is only just starting to recolonise. The boundary between the two generations is indicated with a black dashed line. © BGS, NERC.

Spireslack Locality 17: Devonian strata	**NGR**: [276090, 630849]

Key categories of interest	Rarity	Quality
1. Stratigraphy	★★★★★	★★
2. Sedimentary rocks	★★★	★★★
3. Quaternary deposits	★★★★	★★★★

Access: The face is difficult to access due to a deep pond – access possible elsewhere over very uneven ground.

Current safety: Little evidence for recent rock fall in exposed face, but uneven surfaces and waterlogged conditions underfoot.

Measures to enhance site: Create bridge over pond and even out surfaces to allow easier access. Create viewing platform in front of pond.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Aerial overview of locality 17. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site.

Site Description

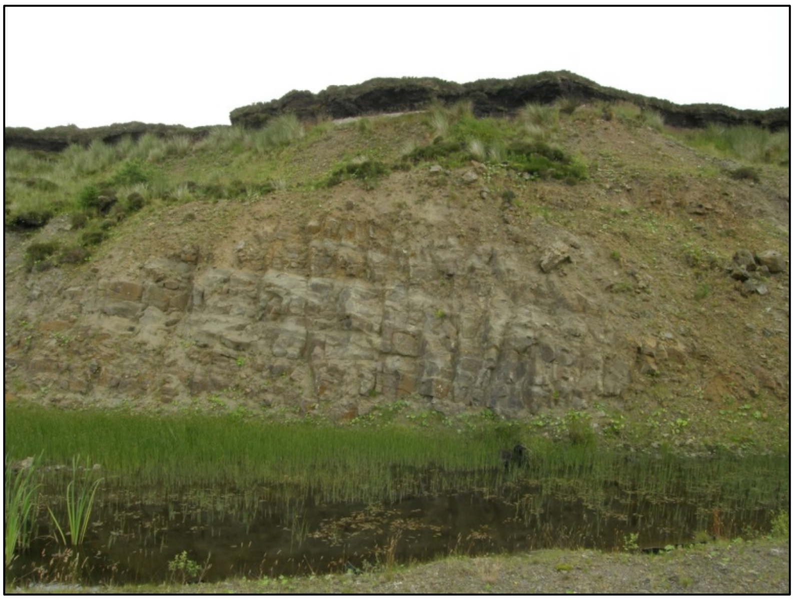
Geology

The merit of this site is in its context: a major fault has displaced the Carboniferous strata against Devonian strata at the far eastern margin of the site, providing a natural cut off for mining operations. Following the Devonian era, which was dominated by fluvial and clastic systems, the Carboniferous saw more swamp-like environments developing, causing the formation of vast amounts of coal. The purpose of this locality in the geodiversity audit is to provide a sense of scale for the site and to illustrate the importance of the Carboniferous strategically within Scotland compared to rocks of other geological periods. The Devonian strata, the Swanshaw Formation at this locality, are composed of massive red-brown medium and coarse-grained terrestrial sandstones with subordinate pebble beds. Peat overlying till is visible above the rock face, although not as accessible in the Quaternary deposits described in locality 16.

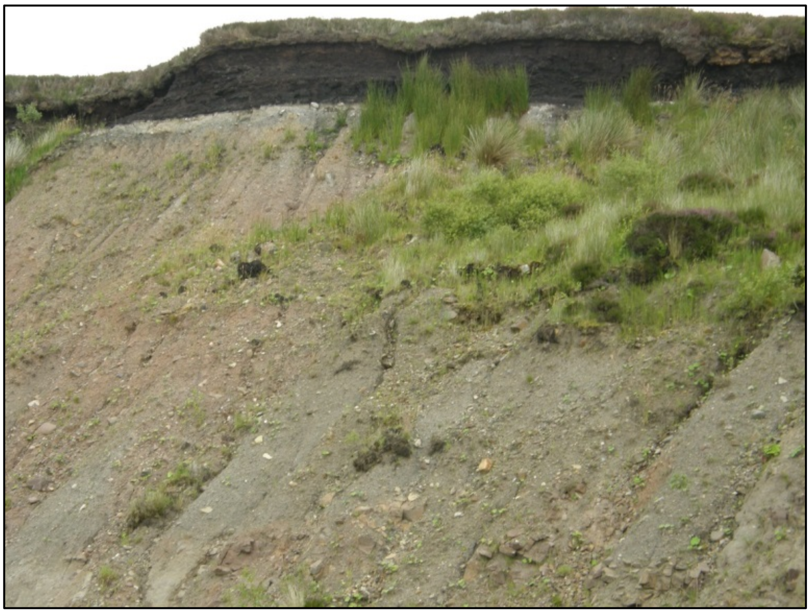
Access and enhancement suggestions

Access is impeded by a pond but an appreciation of the massive sandstone can be given without crossing the pond. Levelling of the ground to provide access to the face and providing a crossing over the pond would enable hands on access to the older strata.

Site Photographs



Spireslack_17 P1: Exposure of the Swanshaw Sandstone Formation, at the eastern edge of the Spireslack SCM. © BGS, NERC.



Spireslack_17 P2: Peat overlying bleached till (formation of podzol) above the Swanshaw Sandstone Formation. © BGS, NERC.

Spireslack Locality 18: 'Area B1' - sedimentary architecture	**NGR**: [74991, 29637] – [75347, 29657]

Key categories of interest	**Rarity**	**Quality**
1. Sedimentary rocks	★★★★	★★★★★
2. Stratigraphy	★★★★	★★★★★
3. Structural geology	★★	★★★★

Access: Good, easily accessible from main car park.
Current safety: Loose blocks on cliff face preclude hands on access. Uneven footing in viewing area.
Measures to enhance site: Flattening of ground in front of face, assess stability of cliff face, platform access for hands on access to the rocks.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only example in Spireslack, 1★ = many examples in Spireslack; Quality 5★ = exceptional preservation in Spireslack, easy access/viewing potential 1★ = average preservation in Spireslack, difficult access/viewing potential

Photograph overview with polygon boundary

Overview of locality 18. Site boundary includes key rock exposures, immediate access to site and viewpoints to the site. View looking toward the north from the old car park levelled area at the south of the Spireslack SCM.

Site Description

Geology

The worked face at 'Area B1', designated from the SCM plans, provides an easily accessible, lateral view of a fluvial sedimentary succession within the Limestone Coal Formation at the southern end of Spireslack. The cliff reveals the internal architecture of a number of channelized sandstones, including cross-bedding, stacked bars, point bars and chute channels – features typical of a fluvial river system, common within this part of the Carboniferous succession. The scarp exposures in the main void of Spireslack also contain fluvial sandstones, but their internal architecture is not exposed as it is here, being fractured (due to underground coal extraction) or covered in rock spall following mining. This locality provides an important section through a typical fluvial succession in the Carboniferous, the likes of which are typically only seen on more inaccessible coastal cliffs or river sections. This locality thus provides an opportunity for teaching and research. The site is best viewed as a whole sequence so as to allow an appreciation for the lateral continuity of units which can then be used as a context in which to place the detail of finer sedimentary features (e.g. cross-bedding and their relation to channels in the sandstone – important for palaeocurrent analysis).

Access and enhancement suggestions

Level area in front of the face and clean up section of loose material and dust to highlight sedimentary features.

Site Photographs

Spireslack_18 P1: Stacked sandstone bodies within Area B1 at Spireslack. These thick tabular massive bodies of sandstone represent stacked bars formed as part of a channel complex. Closer inspection reveals cross-bedding within these stacked bars which can be used for palaeocurrent analysis. To improve access, spoil heap in front section should be levelled and the section cleared of loose material. © BGS, NERC.

3.3.1 Scheduled Monuments within Spireslack SCM

The Glenbuck Ironworks is protected as a Scheduled Ancient Monument, situated in the south of the Spireslack SCM. The designation is shown in Figure 7, and covers the area of bell-pit mines to the south of the main access road (where ironstone was historically mined), and the old ironworks furnace to the north of the road. The ironworks were the earliest phase of mining activity at Glenbuck, and were exploited from 1795 to 1813. The furnace itself is mostly buried beneath mine waste and rubbish but its retaining wall is still visible. The bell-pits are still visible, and have not been covered by more recent mining operations.

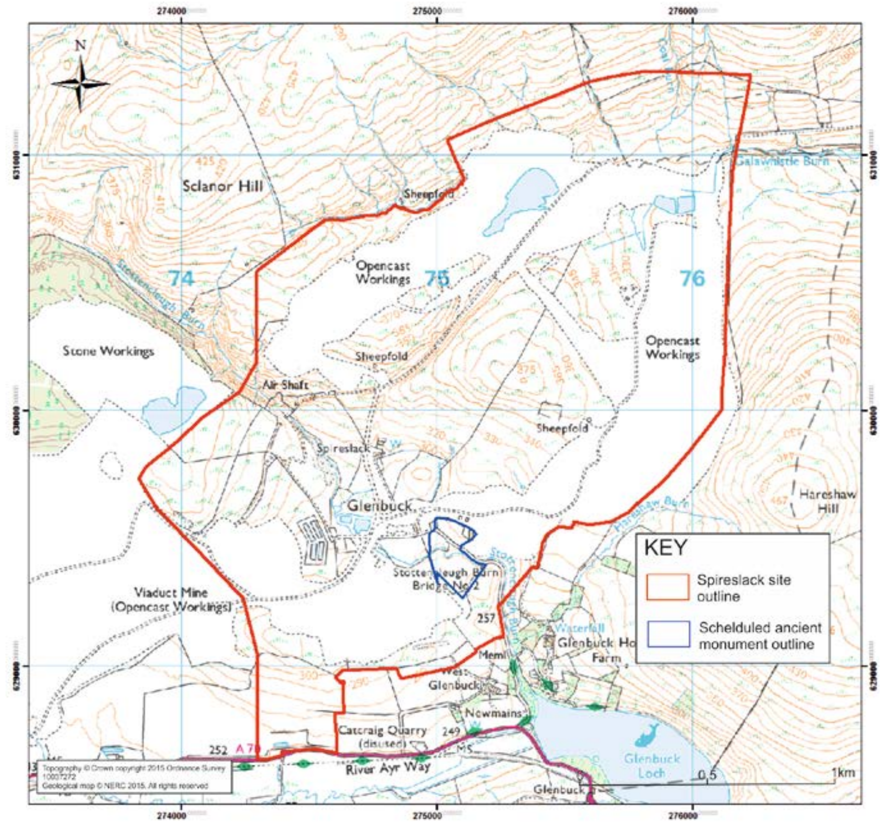


Figure 7: Location map of the Glenbuck Ironworks Scheduled Ancient Monument site. © BGS, NERC

Figure 8: Bell-pits at southern edge of Spireslack SCM. View looking toward the south-west. These disused bell-pits were historically associated with ironstone and limestone mining. © BGS, NERC

Figure 9: The ruins of the Glenbuck Ironworks Furnace are visible at the base of the tree in the centre left of the photo. The furnace has been buried by later generations of mine waste. Photo copyright Mike Browne.

3.4 MAINSHILL WOOD SURFACE COAL MINE

The main face remaining at Mainshill Wood SCM, Douglas (Figure 10), reveals a unique and readily viewable section through over 400 m of sub-vertical strata belonging to the Limestone Coal, Upper Limestone and Passage formations (Figure 11). The strata, at their south-western margin, are contorted into a flower structure, a type of complex fault structure linked to repeated strike-slip movements along the Kennox Fault (cf. Fig 1.3) and related structures. Rather than assign individual geodiversity sections as at Spireslack, the whole of the main face still exposed at Mainshill Wood should be considered as one single geodiversity site, with the main interest focus on structural geology and stratigraphy.

N.B. The geodiversity merit of Mainshill Wood SCM is graded in relation to the region (i.e. Scotland) rather than specific to the site, as there are no particular individual features within Mainshill Wood SCM worthy of individual site designation (unlike at Spireslack SCM).

Mainshill Wood SCM	**NGR**: [285432, 631781]

Key categories of interest	Regional Rarity	Regional Quality
1a. Structural Geology	★★★★★	★★★★★
1b. Stratigraphy	★★★★★	★★★★★

Access: Good access to viewing platform overlooking section. Uneven ground above face. Flooding restricts rock face access.

Current safety: Deep pond, uneven footing, sharp drops.

Measures to enhance site: Level viewing platform, flatten top of exposed face and fence off to allow safe walking access across top of quarry face.

Key categories in order of interest (1 = primary interest); Rarity, 5★ = only well-exposed example within Scotland, Quality 5★ = exceptional preservation in Mainshill Wood SCM, best exposure in Scotland, easy access/viewing potential

Overview with polygon boundary

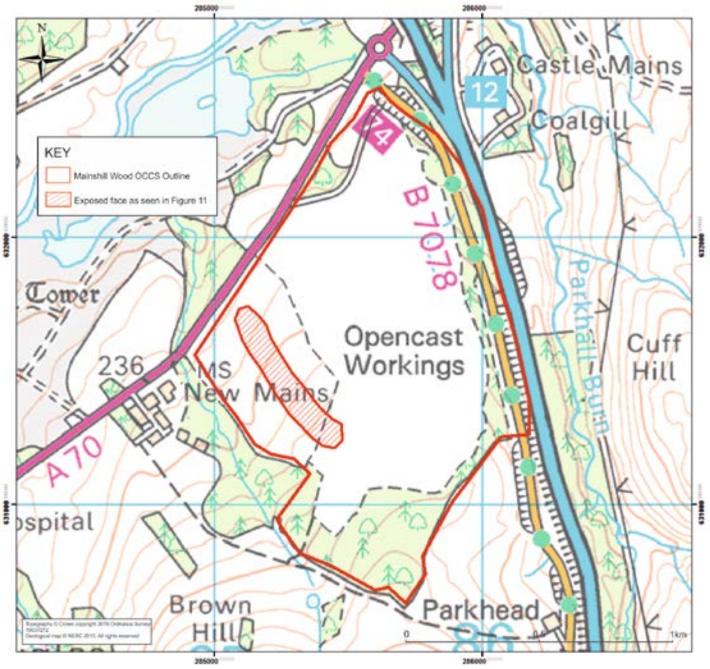


Figure 10: Outline of Mainshill Wood SCM, with extent of exposed face digitised in western sector.

Figure 11: Panoramic photograph towards the south-western corner of Mainshill Wood SCM, revealing spectacular sub-vertically dipping Carboniferous strata. The dark layers are coal seams and mudstones, whilst lighter layers are sandstones and limestones. The rocks are increasingly younger toward the right of the photo (toward the north). Note 4x4 vehicle for scale. Photo taken September 2013 before main void was significantly flooded by groundwater. © BGS, NERC

Site Description

Geodiversity Merit: Structural Geology

It is very unusual for such a thickness of Carboniferous strata to be exposed in one surface mine excavation; at Mainshill Wood this is because most of the strata are now arranged sub-vertically (Figure 12). The section in the Limestone Coal Formation is so disturbed by faulting and folding that arguably the most significant feature of interest for geoconservation, teaching and research is the geological structure rather than the exposed stratigraphic succession. Near the southern back wall of the site, Limestone Coal Formation strata define a series of complex folds and associated faults in a flower structure (Figure 13) - a unique aspect of this site. The junction between the complexly folded strata and the more regularly vertical strata is clearly visible and marked by a conspicuous shear zone where the original continuity of the rock layers is virtually destroyed. All of these units and structural features could eventually be safely examined at close quarters given carefully designed partial restoration.

Geodiversity Merit: Stratigraphy

The process of extracting coal from sub-vertical seams is extremely rare, and the resulting exposure of coal-bearing strata at Mainshill Wood, has few equivalents in Scotland, the UK or further afield. The stratigraphic succession exposed at Mainshill Wood SCM includes at least eleven locally named coal seams, many of which are not naturally exposed at surface in Scotland (see Figure 2 for generalised vertical section through the rocks exposed at Mainshill Wood). The section in the Upper Limestone Formation reveals the Index, Huntershill (or Birchlaw), Lyoncross (Tibbie Pagan's), Orchard, Calmy (Blue Tour) and Plean limestones as well as the Ellenora and Gill coals. The exposed section in the Passage Formation is unique (in Scotland, to which it is restricted geologically) and known otherwise only from the records of a few boreholes drilled to prove deep coal seams. The occurrence of three thick Manson Coal seams (Figure 14) totalling some 7.8 m in 11.5 m of associated shelly marine mudstones, is in sharp contrast to occurrences elsewhere in the Central Scotland coalfields where the Passage Formation normally contains only a few coal seams up to about 30 cm thick. No natural exposures of the Manson Coal strata exist. As at Spireslack, fossilised shells and plant fragments are to be found amongst the rocks exposed here.

Access and Enhancement suggestions

The water level at Mainshill Wood SCM is currently at a high level, preventing hands on access to much of the exposed face. The roadways are now underwater in most instances, and the benches appear not to be safe to walk on. However, much of the impact of Mainshill Wood SCM impact comes from its visual character – when the site is viewed from the opposite 'shore', the 'barcode' effect of the sub-vertical coal-bearing strata is visually striking, as is the truncation of this strata thanks to the faulting at the south-west margin. Therefore a dedicated viewing platform overlooking the far wall would greatly enhance an appreciation of the strata along with interpretation boards. For facilitating hands on access, there is access along the top of the main face where the overlying glacial till has been scraped back from rockhead around 5 m away from the face, allowing the inclined sequence to be walked over from youngest to oldest (heading south). This walkway, if cleared, levelled and fenced off from the steep drop to the main face would provide safe hands on access to the strata. The walkway could be enhanced by polishing up key sections of rock to allow a detailed view of the characteristics of the different rock types along the section.

Site Photographs

Figure 12: Main face of Mainshill Wood SCM showing the sub-vertical strata. The darker layers visible in the mined face are coal seams (the Manson Coals in the centre of the image), whilst the lighter layers are sandstones and limestones. Note high water level restricting access to base of exposures. Photo taken June 2014. © BGS, NERC

Figure 13: View toward the south-west corner of the Mainshill Wood SCM main face, revealing the flower structure related to the Kennox Fault. The flower structure is the area of folded and faulted strata to the left of the inclined strata in the photo. © BGS, NERC

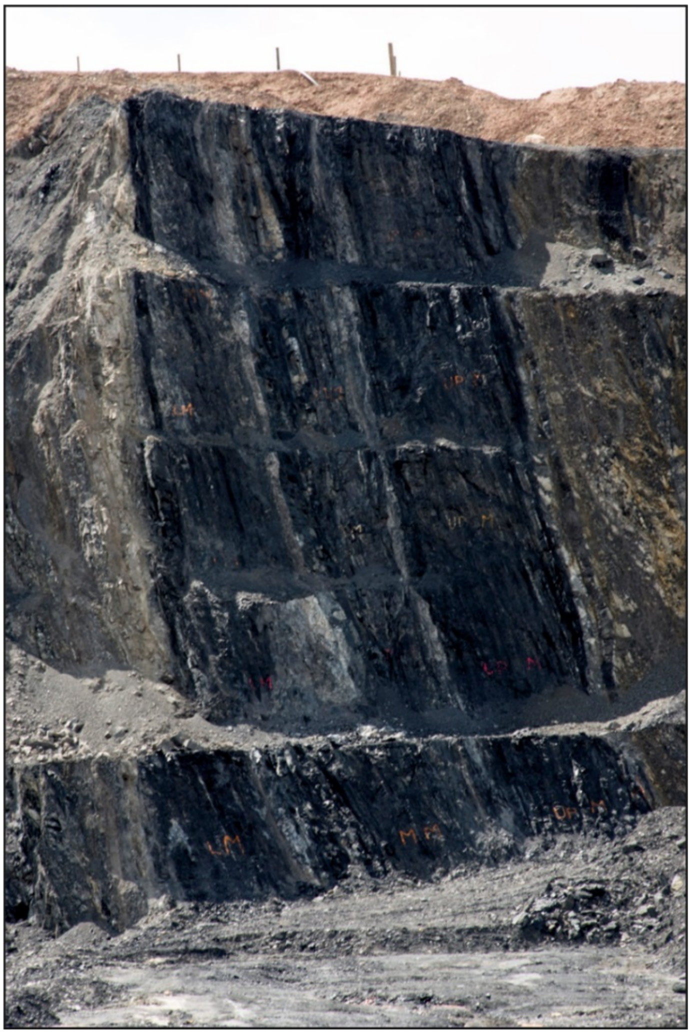


Figure 14: The Manson Coals seen in the main face at Mainshill Wood SCM. From left to right, the Lower, Middle and Upper Manson Coal seams. The Manson Coals are not seen elsewhere in natural sections; therefore Mainshill Wood SCM provides the only opportunity to study these coals. © BGS, NERC

Notes:

4 Conclusions and Recommendations

4.1 CONCLUSIONS

Mainshill Wood and Spireslack SCMs were evaluated for their geodiversity potential.

1. A total of 18 sites of geological interest were assessed within the Spireslack SCM and are recommended as local geodiversity sections that should be prioritised for preservation.
2. The entirety of the exposed face in the south-west corner of Mainshill Wood was assessed and also recommended as a geodiversity site to be prioritised for protection.
3. Combined, the sites provide access to, and spectacular exposures of, a range of Carboniferous strata, structures and fossils otherwise seen at limited natural outcrop, as well as highlighting the economic importance coal has had on Scotland's industrial heritage.
4. Many of the local geodiversity sections within Spireslack SCM, and the main wall at Mainshill Wood SCM, could be enhanced to encourage visitors, students and researchers to learn about the Carboniferous era and about the rich link the Central Belt of Scotland has with coal mining.

4.1.1 Spireslack SCM

The recommended geodiversity sections at Spireslack SCM contain a range of excellent exposures of the following key geological interests:

- Sedimentary rocks: e.g. seatearths and marine bands not often found in natural section, or a visual appreciation of channel morphology;
- Stratigraphy: e.g. the whole of the Limestone Coal Formation is exposed along a 1 km section: nowhere else in Scotland is a complete sequence through this formation seen;
- Palaeontology: e.g. easily accessible crinoids, trace fossils, tree roots and tree casts, as well as rarer fossils such as the shark spine and trilobite fossils;
- Igneous rocks: e.g. 3-D appreciation of intrusive dykes and their effect on the surrounding rock;
- Structural geology: e.g. world-class 3-D exposures of complex fault zones and their relations with rocks of different strengths;
- Mineralisation: e.g. calcite mineralisation associated with faulting the limestone pavement and intrusion of magma;
- Quaternary geology: e.g. sections through thick peat deposits overlying glacial till, revealing soil forming processes important to landscape evolution;
- Economic geology: e.g. cross-sections through collapsed underground mine workings, where pit props and rock pillars are visible in situ;
- 3D Visualisation: e.g. faults, dykes and sedimentary structures can be followed in a 3D space rather than the usual 2D section available in the field.

4.1.2 Mainshill Wood SCM

Mainshill Wood SCM reveals sub-vertical sequences through the Limestone Coal, Upper Limestone and Passage Group formations, the complete sequence of which is not visible in natural sections in Scotland.

- Thick coals developed within the Passage Group (the Manson Coals) are exposed nowhere else in Scotland.
- The Mainshill Wood SCM also reveals the internal architecture of a flower structure, formed during multiple movements along the Kennox Fault, a major strike-slip fault. Such flower structures rarely seen and preserved in nature.

Combining these exceptional exposures of Carboniferous strata and the economic heritage of the area with already protected SSSI and GCR (geological conservation review) sites (covering the Silurian era) in the surrounding area, provides real potential for developing the region into a Geopark.

4.2 RECOMMENDATIONS

1a. There are key geological sites that should be preserved within the Spireslack and Mainshill Wood SCMs. These sites would benefit from a degree of remedial work designed to enhance their appearance, and to provide safe access. Inspections should be undertaken by suitably qualified personnel, and remedial measures undertaken as recommended.

1b. Any redevelopment of Spireslack or Mainshill Wood SCMs should protect the geodiversity sections and sites outlined in this audit.

1c. Both sites should be considered for designation as at least Local Geodiversity Sites (as defined by GeoconservationUK), and potentially for GCR status (see section 1.4).

1d. This audit could, and arguably should, readily be extended across the Ponesk area in order to provide a rigorous geological assessment across the entire Spireslack/Ponesk complex.

2a. The addition of geological information to the potential redevelopment of both of these remarkable sites, along with sign boards, leaflets, online information (e.g. accessible website and/or smartphone application) and the creation of local geo-trails within each SCM would increase access to geological information about the sites for a range of potential community, educational and research users.

2b. The range of individual sites can be augmented with facilities, signage, safe and good access to the site as a whole, all with a view to delivering a good teaching and/or visitor experience.

2c. Some of the sites may be suitable for responsible fossil collection, if managed appropriately. The Scottish Fossil Code should be consulted and followed with regards to this. A copy of the current Scottish Fossil Code can be found on the following website: http://www.snh.gov.uk/protecting-scotlands-nature/safeguarding-geodiversity/protecting/fossil-code/

3a. In order to make the best of the opportunities presented to the geoscience research community at both Spireslack and Mainshill Wood SCM, BGS proposes the creation of the **S**cottish **Ca**rboniferous **R**esearch **P**ark (SCARP), to facilitate a natural 3D laboratory and learning platform. BGS are very keen to support this enterprise but recognise the need for careful management of the site(s) to maximise research potential, avoid conflicting uses, and sustain their safe and effective operation, potentially in parallel with other non-scientific, and perhaps leisure-based uses.

3b. In relation to the above, BGS recommend that a small and focused management group of key personnel delivering critical expertise be identified, including the BGS and reporting directly to SMRT. This group should be tasked with taking this SCARP opportunity forward as a national asset – seeking to identify future partners, sources of funding, an appropriate future stewardship model, and overseeing Health and Safety requirements.

Appendix 1

This Appendix summarises details of sites within Spireslack SCM (Figure 15), which are of lesser quality than the 18 sites included in the audit, but are worth recording. These are described briefly below and should be considered as a second priority for protection than those included in the main audit.

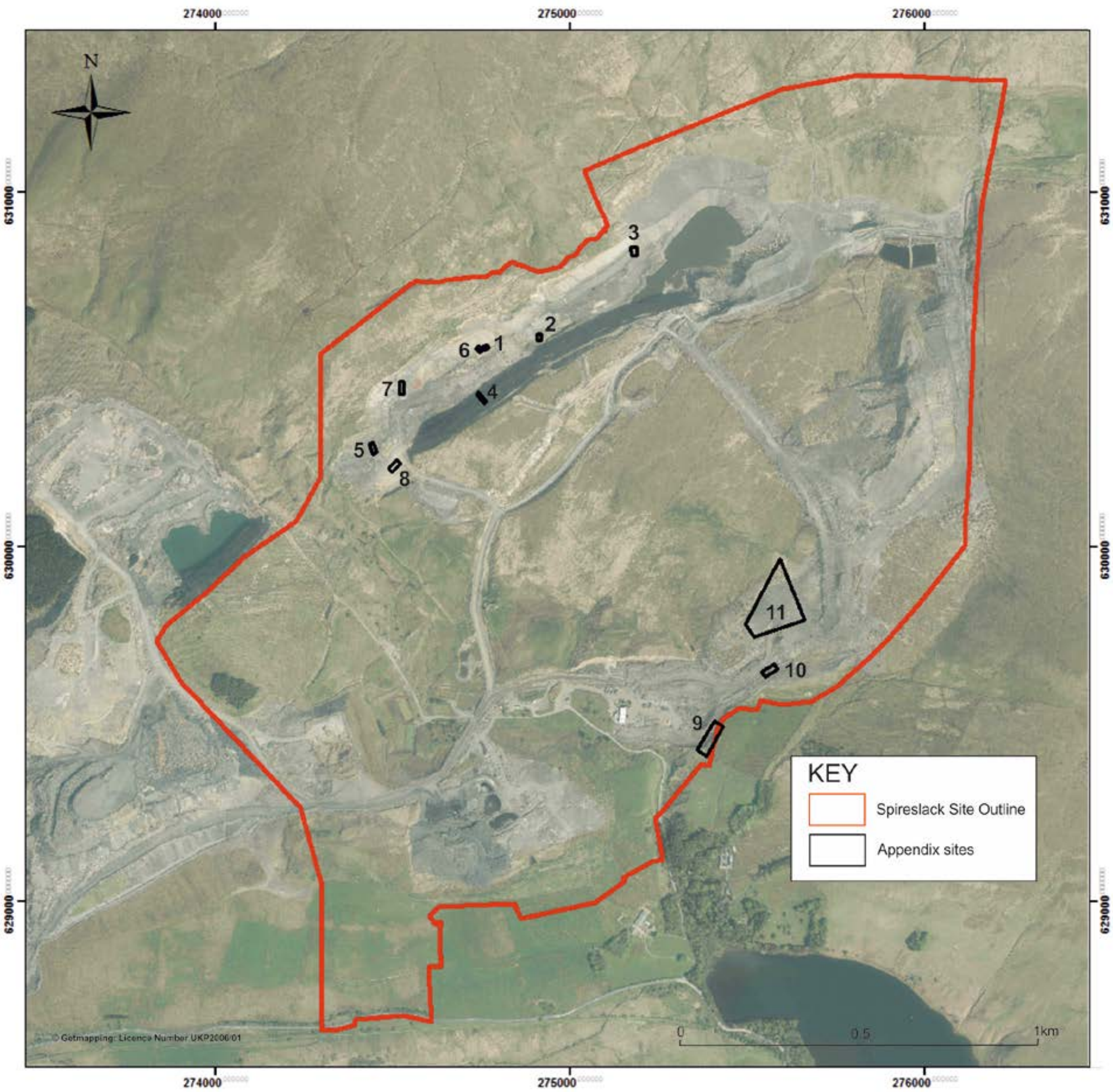


Figure 15: Location of sites within Appendix 1 at Spireslack SCM.

1. **Drill hole in limestone pavement, NGR 274758 630557**. Hole drilled in limestone to relieve pressure from build-up of water behind the pavement. Economic geology interest.
2. **Sequence of poor-quality coals, siltstone and ironstone nodules, NGR 274913 630591**. Sedimentary and stratigraphic interest.
3. **Faulted sequence beneath McDonald seatearth, NGR 275187 630824**. Ironstones and mudstones affected by faulting and mineralisation. Structural and sedimentary interest.
4. **Thin dyke, NGR 274748 630432**. Another of many thin dykes intruding the Limestone Coal Formation. Igneous interest.

5. **Sequence beneath McDonald seatearth, NGR 274447 630266**. Another exposure of the McDonald seatearth and sequence beneath. Sedimentary and stratigraphy interest.
6. **Small displacement fault, NGR 274736 630542.** Another example of many low displacement faults cutting the McDonald Limestone, with associated mineralisation. Structural and mineralisation interest.
7. **Fault at western end of Spireslack, NGR 274517 630430**. The juxtaposition of the McDonald and the Hurlet Limestone, caused by a fault at the western edge of the site, is observed at this locality. Structural interest.
8. **Index Limestone, NGR 274487 630214**. The road surface intersects the trace of the Index Limestone here, allowing hands on access to limited exposures. Sedimentological and palaeontological interest.
9. **Fault juxtaposing Limestone Coal Formation against Lawmuir Formation, NGR 275391 629463.** The trace of the fault intersects the eroded back wall of the Spireslack SCM, conspicuous by a red staining of the rocks there. Structural interest.
10. **Large blocks with gigantus productids, NGR 275560 629654.** A collection of quarried limestone containing abundant layers of Giganto productids, good for teaching purposes. Palaeontological interest.
11. **Large monoliths across Spireslack SCM, NGR 275578 629817**. Large rock monoliths containing excellent examples of cross-bedding in sandstones and bioturbation in seatearths – potential for onsite ‘geo-trail’ marked by these blocks. Sedimentary interest.

Glossary

Ankerite	A calcium, iron, magnesium, manganese carbonate mineral
Anthropocene	Recognized as the present geological period where human activities now have a pronounced influence on geological conditions and processes.
Anoxic	Depleted of dissolved oxygen
Bedding	A feature of sedimentary rocks, in which planar or near-planar surfaces known as bedding planes indicate successive depositional surfaces formed as the sediments were laid down.
Bioturbation	The disruption of depositional sedimentary structures by organisms e.g. activities such as burrowing.
Bivalve	Class of molluscs with paired oval or elongated shell valves joined by a hinge (e.g. mussels).
Brachiopods	A phylum of solitary marine shelled invertebrates, the shell is made up of two unequal valves.
Breccia	A coarse-grained clastic rock composed of angular rock fragments. Breccias are formed in sedimentary and volcanic environments, and via tectonic processes.
Calcite	Calcium Carbonate [$CaCO_3$] a widely distributed mineral and a common constituent of sedimentary rocks, limestone in particular. Also occurs as stalactites and stalagmites and is often the primary constituent of marine shells.
Calcareous	Containing calcium carbonate.
Carboniferous	A geological period [359–299 Ma] of the Palaeozoic Era preceded by the Devonian and followed by the Permian.
Carbonaceous rocks	Sedimentary rocks containing significant enrichment in organic matter (carbon).
Chilled margin	The fine-grained outer layer of an igneous body formed by rapid cooling.
Conglomerate	A coarse-grained clastic sedimentary rock, a significant proportion of which is composed of rounded or subrounded pebbles and boulders.
Conjugate faults	A set of faults at opposing angles (the angle of which varies depending on mode of faulting), developed synchronously.
Conchoidal	A smooth, curved surface similar to the interior surface of a shell.

Crinoid	A sea dwelling creature (class Crinodea) which has survived since Ordovician times. They are known as sea-lilies and have three sections, the stem, the calyx and feather-like arms by which they collect food. There abundance in the Palaeozoic era has meant that their remains have formed large thicknesses of limestone due to their calcareous skeletons.
Cross-bedding	Sets of strata which are inclined to the general stratification of the beds. They dip in the direction of fluid flow at the time when the beds were laid down.
Deltaic	A depositional environment where a river enters into an area usually the ocean, where the flow is zero leading to the river sediment being deposited, and finer grained material is usual farther out into the lake or ocean, (distal).
Devonian	A geological period [416–359 Ma] of the Palaeozoic Era preceded by the Silurian and followed by the Carboniferous.
Diagenesis	All physical, chemical and biological processes that occur in sediment after deposition and before metamorphism. It does not include weathering.
Dip-slip fault	A fault with a vertical component of displacement.
Dolerite	A medium grained intrusive igneous rock chemically similar to basalt but due to a slower cooling rate than basalt, crystals can be seen with a hand lens. It usually occurs as dykes, plugs or sills.
Dyke	A sheet-like body of intrusive igneous rock emplaced along a vertical or near vertical fracture, normally discordant to the structure in the country rocks.
Fault	A fracture in the Earth's crust across which the rocks have been displaced relative to each other.
Fault plane	A vertical or dipping surface of a fault.
Fault zone	A zone of tectonically deformed and broken rock representing the surficial expression of a fault. The zone can comprise of fault rocks, slip surfaces, fractures and mineralisation, and may be weaker or stronger than the strata the fault displaces.
Fissile	A term used to describe a rock which is easily split.
Flower structure	A group of upwardly diverging faults formed in strike-slip fault zones.
Fluvial	Referring to a river environment.
Fold	A bend in planar structures such as rock strata or bedding planes.
Footwall	The strata found in the plane beneath a fault.

Formation	The fundamental unit used in lithostratigraphy. Specific features distinguish one formation from another. Formations may be subdivided into members and several formations may constitute a group.
Geomorphology	The study of landforms and the processes that form them
Hanging wall	The strata found in the plane above a fault.
Igneous rocks	A rock that has formed from the cooling of magma (molten rock).
Intrusion	A body of igneous rock which has been injected as magma into existing hard rocks (country-rock). On cooling the magma is called an igneous intrusion.
Joints	A fracture, or potential fracture, in a rock adjacent to which there has been no displacement.
Limestone	Sedimentary rock composed mainly of calcium carbonate.
Lithified	Unconsolidated sediments which have gone through the process of forming solid rock.
Lithology	The character of a rock expressed in terms of its mineral composition, structure, grain size and arrangement of its constituents.
Lithostratigraphy	The branch of stratigraphy concerned with the description of rock units in terms of their lithological features and spatial relationships.
Ma	Abbreviation for megannum (or more correctly, megannus) meaning million years
Magma	Molten rock.
Oblique slip fault	A fault which has a component of dip slip and strike slip combined – i.e. a mixture of horizontal and vertical movement.
Paleogene	Geological Period: 66 to 23 Million years ago
Paleozoic	Geological Era: 541 to 252 Million years ago
Quartz	The mineral form of silicon dioxide (SiO_2). The most abundant and widespread of all minerals, it generally appears transparent or white and is hard enough to scratch glass.
Quartz dolerite	A basic, fine grained intrusive igneous rock containing quartz
Quaternary	A geological sub-era [2.6 Ma to present day] of the Cenozoic Era, following the Neogene.
Relay ramp	The overlap zone between two linked fault segments
Seat earth	A sedimentary rock underlying a coal seam representing an old soil that supported the vegetation from which the coal has formed.

Sedimentary rock	A rock formed in one of three main ways: by the deposition of the weathered remains of other rocks (clastic sedimentary rock); by the deposition of the results of biogenic activity; and by precipitation from solution. Four basic processes are involved in the formation of a clastic sedimentary rock: weathering (erosion),
Sinistral	A left-lateral sense of motion along a fault plane
Slickensides	A polished rock surface, usually displaying linear grooves and ridges (slickenlines). Found on fault planes and caused by the movement of adjacent blocks of rock.
Stigmaria	Root system of trees
Strata	Rocks that form layers or beds.
Strike-slip fault	A fault with a horizontal component of displacement
Stratigraphy	The definition and description of the stratified rocks of the Earth's crust.
Syncline	A U-shaped fold containing stratigraphically younger rocks in its centre.
Talus	A sloping accumulation of loose clasts generally in the form of a wedge, usually found at the base of a steep rock face.
Thrust faults	A reverse fault, typically low angle.
Trace fossil	A fossilized track or burrow formed by animal movements in soft sediments, preserved in the rock record.
Vein	A fracture in the rock infilled with secondary minerals, often quartz or calcite.
White trap	An alteration product of basic igneous rocks following intrusion into carbon rich rocks (e.g. coal).

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