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UK Structure Site Report: Howick

British Geological Survey

BGS REPORT NUMBER: OR/25/038

Abstract

Understanding the architecture and connectivity of faults and fractures is important for multiple end users, including engineering geology and construction; and controls on groundwater flow and fluid compartmentalization. The Howick site on the Northumberland coastline provides an excellent lateral and vertical cross-section through two faults, the Howick and Culvernose faults. The Howick fault juxtaposes the Stainmore Formation (interbedded mudstone, sandstone, and siltstone) against the Alston Formation (interbedded limestone and thin mudstone), while the Cullernose fault juxtaposes the Alston Formation against the Whin Sill. Lithology controls fault attitude, and where conjugate faults meet, the intersection zone is highly fractured and faulted. The faults show a penecontemporaneous relationship with the Whin Sill complex, suggesting faulting occurred during and after magma emplacement.

Statement of Intent

This work was undertaken as part of the British Geological Survey's National Geoscience UK Structure programme.

The data pack is intended as a resource that provides an overview of fault structure and fault network architecture, using an example from Howick, Northumberland. The work highlights the complexity of major faults that is not resolvable on 1:50 000 and 1:10 000 scale geological maps, where faults are expressed as a single line. The data pack can be used as an analogue for understanding potential fault networks in the subsurface in similar stratigraphic packages. The data pack focusses on horizontal and vertical sections along the coastal foreshore.

Bibliographical reference

VERNON, R., STEPHENS, T. L., PAUL., P., HASLAM, R. 2026. UK Structure Site Report: Howick. *British Geological Survey Open Report*, OR/25/038. 19pp.

BGS Report No. OR/25/038

BGS Project Code: NEE7165S

Front cover photo: Overview of Crag Point Fault Zone facing West. The main fault juxtaposes a thick sandstone package against interbedded sandstone, shale, and coal units. BGS image P1079679 © UKRI 2024.

Report Issued: 19/01/2026

This report uses Cardinal Coordinate notation when referring to dip directions or trends of features, e.g.:

- **N** north
- **NE** north-east
- **NNE** north-north-east
- **N-S** north-south

Regional Setting

The Howick site is situated near to Alnwick to the north of the Northumberland-Solway Basin. The Northumberland-Solway Basin represents an early Carboniferous syn-deformational depocentre in the Variscan Orogenic foreland region of Northern Britain, which spans the Iapetus Suture Zone. It is characterised by a series of ENE-WSW trending basins and structural highs bound by listric normal faults, often with significant offset, formed during late Devonian to early carboniferous during N-S to NNW-SSE directed extension and rifting (Leeder, 1975; Collier, 1989).

The Northumberland-Solway Basin is bound to the north by the Cheviot Block and to the south by the Alston Block, two structural highs which are cored by Caledonian granite batholiths (Howell et al., 2022). These highs have thin Carboniferous cover (~500 m), while depocentres within the Northumberland Basin contain Carboniferous sequences up to 4 km thick (De Paola et al., 2005).

Post-Variscan NE-SW extension began in the Permian and continued into the Mesozoic. Collapse of the Variscan Orogen imposed a dextral-transtensional regime on the inherited ENE-WSW Variscan faults (Collier, 1989).

Strata across the Northumberland Basin has a general regional dip of ~10° southeast, though faulting and folding causes local variations (Shiells, 1964). De Paola et al. (2005) suggested that the fault distribution in the Northumberland Basin represents local partitioning of a transtensional stress regime into a wrench-dominated domain across the Cheviot Block and an extension-dominated domain in the Northumberland Basin.

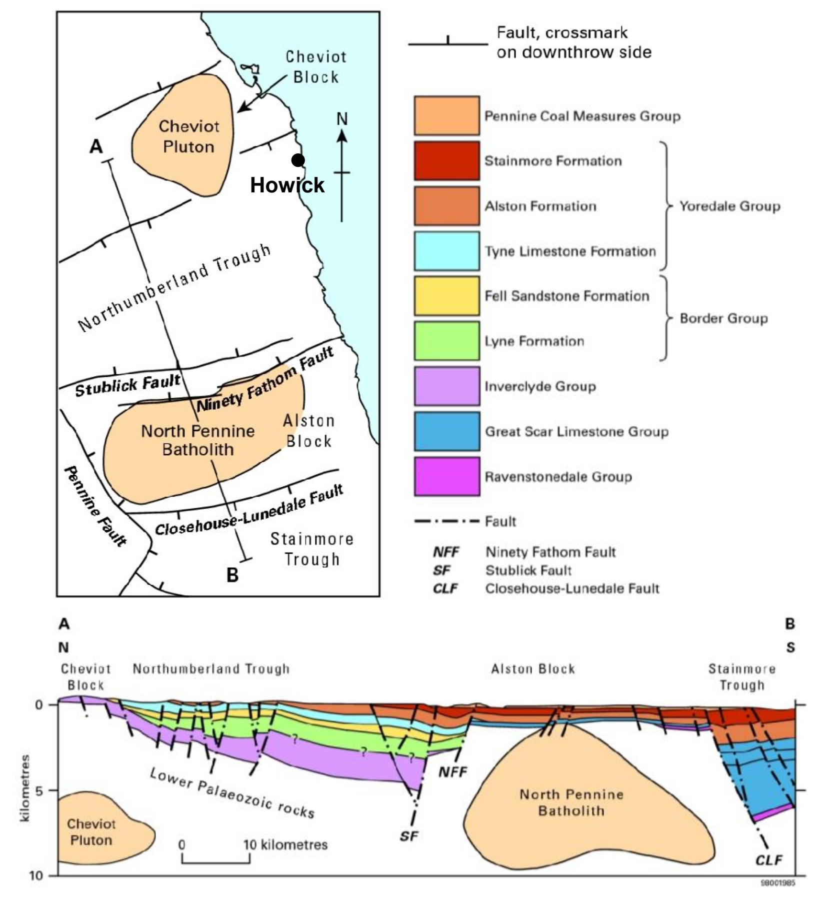


Figure 1. (a) Schematic map and cross-section showing the block and basin structure of the Northern Pennine Basin. Figure from Stone et al. (2010). British Geological Survey © UKRI 2010.

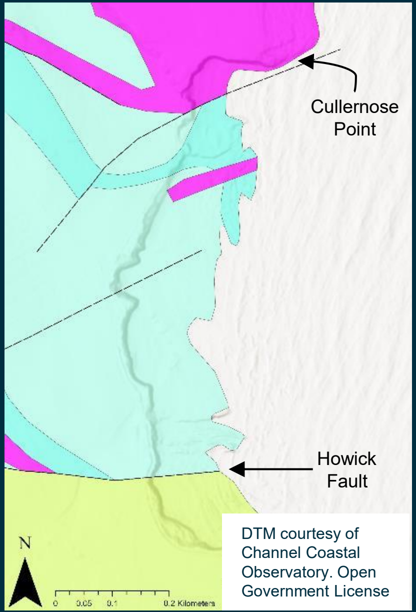
Site Description

The Howick Site comprises a coastal section extending ~1km to the south of Cullernose Point. The coastline exposes Carboniferous (Namurian ~331-319 Ma) rocks of the Alston Formation and Stainmore Formation which are intruded by the ca. 297 Ma Whin Sill Complex (Liss et al., 2004).

Whin Sill Complex: The complex is composed of dolerite and micrograbbro intruded as sills and dykes which cross-cut bedding in the host rock.

Stainmore Formation: The formation is composed of interbedded mudstones, sandstones and siltstones, with subsidiary limestones and occasional coal beds.

Alston Formation: The Four Fathom Limestone Member forms the uppermost part of the formation at the site and is composed of interbedded mid-dark grey, fine-grained, sometimes argillaceous, packstone limestones and thin mudstones. The underlying parts of the formation composed of interbedded sandstones, mudstones, limestones and siltstones. Cross-bedded packages of sandstones several metres thick are present, particularly in the northernmost part of the site.



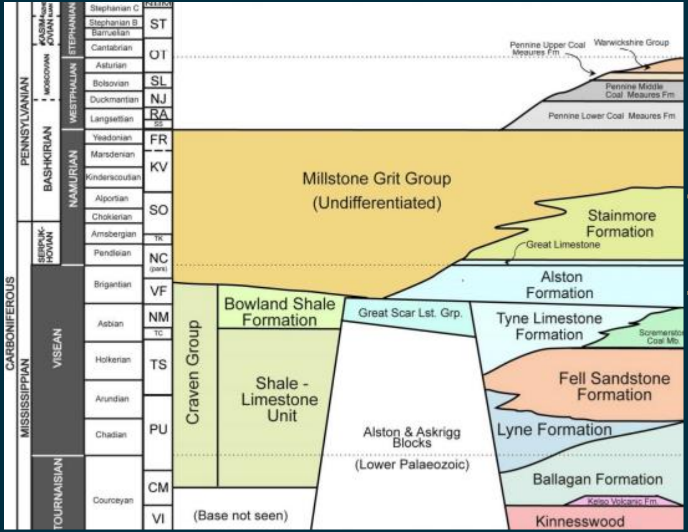
Whin Sill Complex

Stainmore Formation

Four Fathoms Limestone Member

Alston Formation

BGS 1:50 000 scale bedrock geology of the Howick Site.



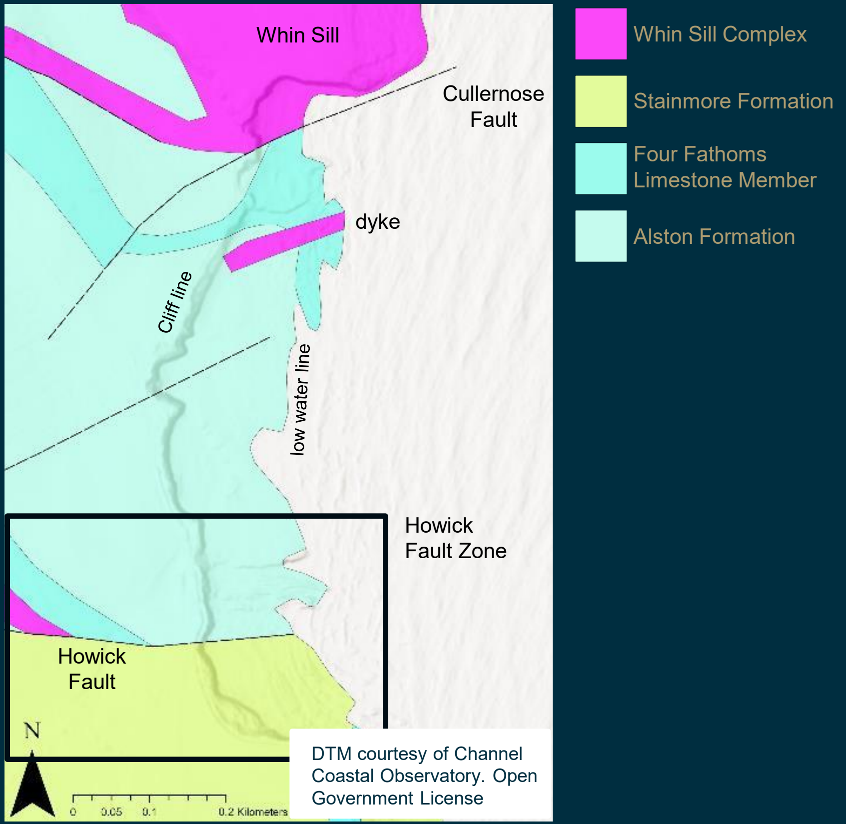
Approximate Howick stratigraphic interval

Schematic north – south cross-sections showing the Carboniferous and Devonian strata of northern England. From Kearsey et al. (2015), British Geological Survey © UKRI 2015.

Howick Faults

Two main faults are exposed in the Howick Section;

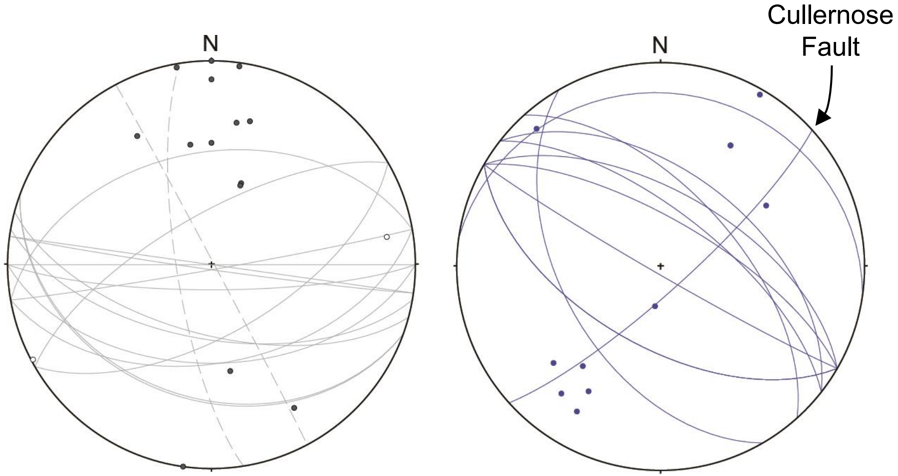
- The Howick Fault Zone is c.100 m wide and comprises multiple E-W trending faults in both the hangingwall and footwall of the main fault (DePaola et al., 2005). The fault zone juxtaposes the Alston Formation, to the north, against the Stainmore Formation, to the south. It is suggested to have a throw of around 200 m (Westol et al., 1955) and may also have a dextral strike-slip component (Farmer and Jones, 1969). De Paola et al. (2005) suggest the subsidiary hangingwall faults are syn-sedimentary due their listric geometries and soft sediment deformation. On the foreshore, E-W faults are observed cutting the Alston Formation, linked by NE-SW trending faults. Two sets of slickenlines, steeply inclined and shallowly inclined, suggest two distinct modes of slip: a normal extensional regime and dextral transtensional regime (DePaola et al., 2005).
- The Cullernose Fault is made up of a main NE-SW trending fault with a number of subsidiary faults oriented at a low to moderate angle to the main fault. The main fault offsets the Alston Formation, juxtaposing the lower cross-bedded sandstone and mudstone/coal beds of the formation against the interbedded limestones and mudstones of the Four Fathoms Limestone Member at the top of the formation. The displacement of the fault is estimated to be tens of meters, based on the stratigraphy of the Alston Formation. The fault also appears to truncate the thick Whin Sill which only crops out inland to the southwest, although dykes associated with the sill are present.



BGS 1:50 000 scale bedrock geology of the Howick Site giving a simplified overview of the fault systems.

Field Observations - Overview

Four fault and fracture zones have been identified in the Howick coastal section during this study. The southern zone (A - the Howick Fault Zone) consists of a zone of high-density, E-W trending faults. The three zones to the north (B, C & E) however, are oriented NE-SW. The middle two zones (B & C) are composed of disparate minor faulting and fracturing with very little offset. The northern zone (E - the Cullernose Fault) is a major NE-SW striking fault with a number of minor subsidiary faults trending NW-SE to WNW-ESE.

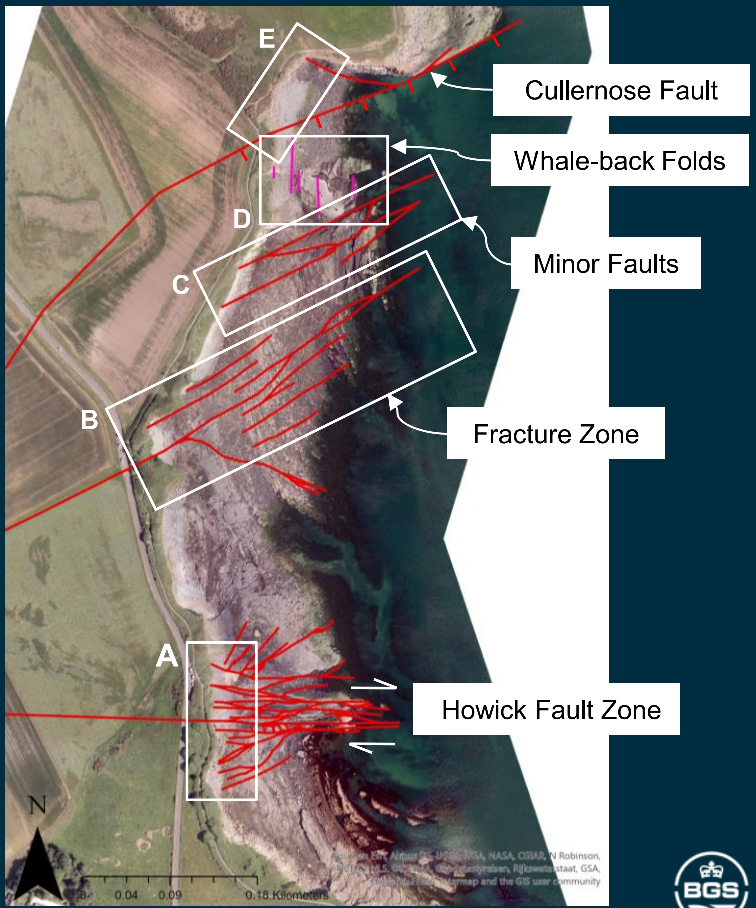


Howick Fault Zone faults (poles and planes) (n=14)

deformation bands (poles and plane) (n=2)

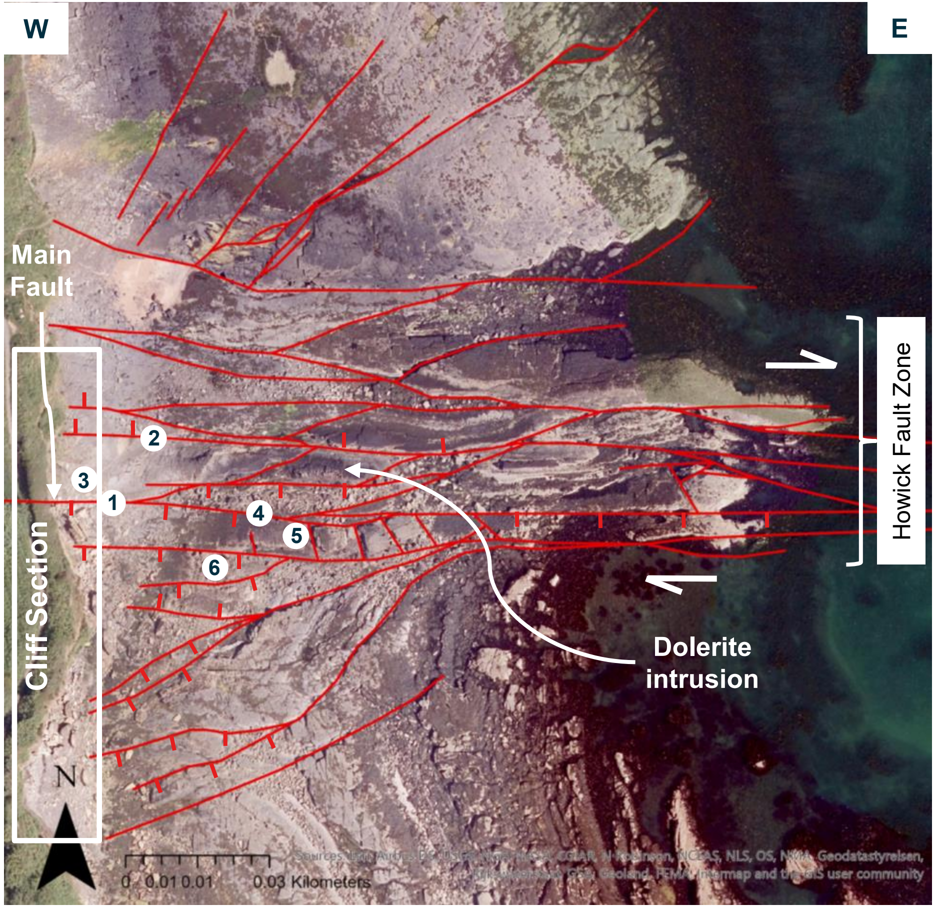
faults cutting Whin Sill (poles and plane) (n=11)

Howick Coast Site



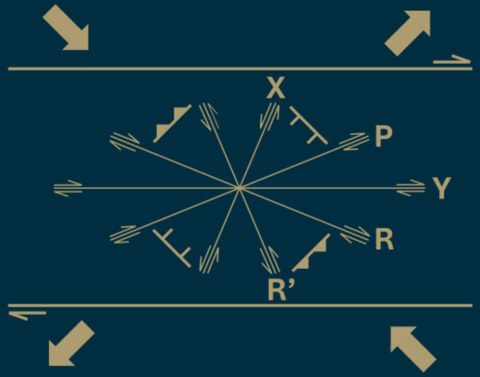
Aerial imagery courtesy of National Network of Regional Coastal Monitoring Programme © 2026 NNRCMP

Field Observations - Plan View



A - Howick Fault Zone

The Howick Fault Zone can be observed in cliff section and plan view on the coastline east of Howick. The fault zone is ~ 60 m wide and consists of a number of predominantly E-W trending faults which are linked by a network of shorter, connecting ENE-WSW trending faults and NNW-SSE fractures which could be consistent with P and R' shears in a dextral-transtensional stress regime.



< Dextral-transtensional riedal shear model, showing the predicted modes of slip on faults of different orientations within the fault zone.

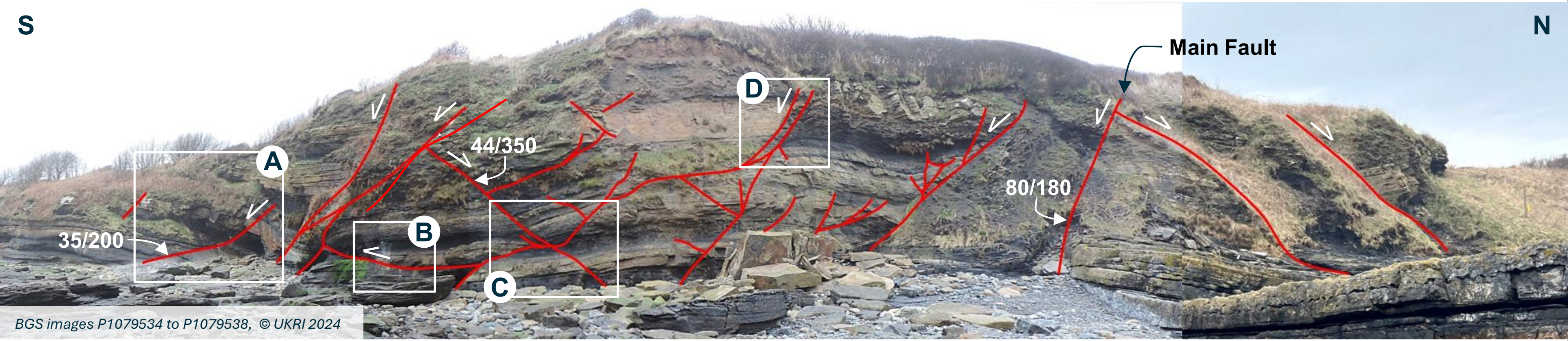
To both the north and south of the fault zone several NE-SW oriented fractures splay from the fault zone. The faults to the south of the main fault zone are also exposed in the cliff section.

A small volume of dolerite, associated with the Whin Sill, is present as a lense within the fault zone. De Paola et al. (2005) suggest that the restricted nature of the intrusion, and the lack of deformation within the intrusion imply emplacement was likely to be contemporaneous with faulting.

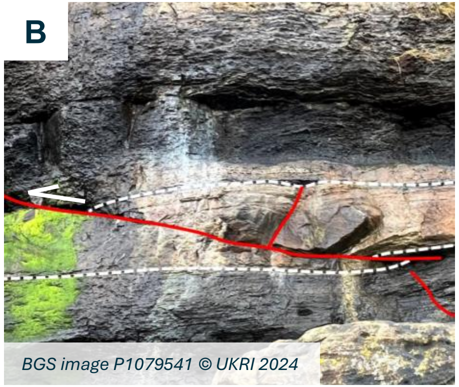
Field Observations – Cliff Section

A - Howick Fault Zone

Photographs of the cliff section Located on slide 7.



↑ Low angle normal fault with a breached relay zone through the weaker mudstone bed.



↑ Very low angle reverse fault connecting two south-dipping normal faults and offsetting a sandstone.

↑ Relay zone, mostly where a north-dipping and south-dipping normal fault intersect.

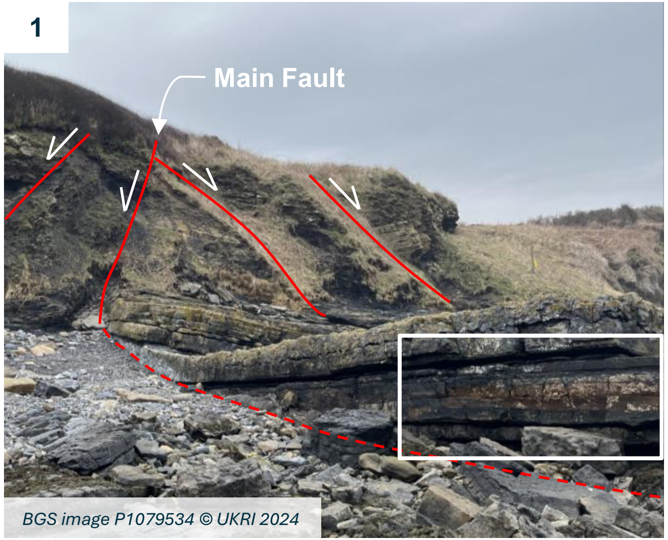
↑ Multiple fault planes associated with a south-dipping normal fault.

Field Observations - Mineralisation

A - Howick Fault Zone

Photographs from Locations 1, 2 and 3 on slide 7.

1

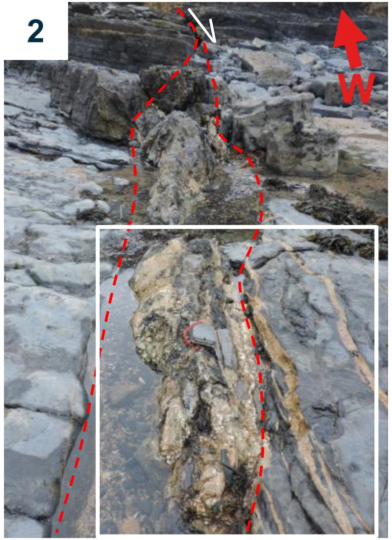


BGS image P1079534 © UKRI 2024

BGS image © UKRI 2024

↑ Polished fault surface with calcite mineralisation.

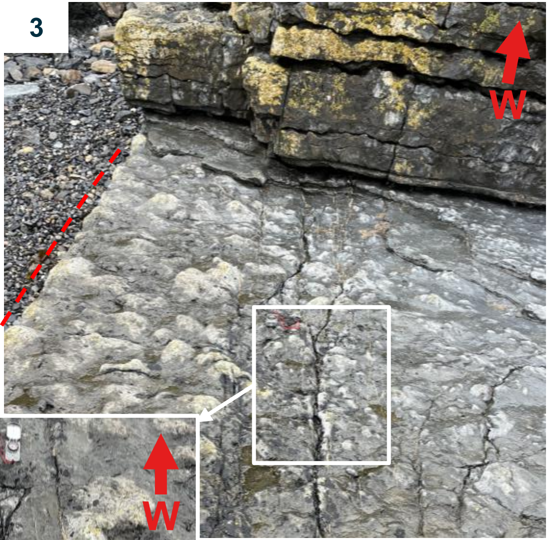
2

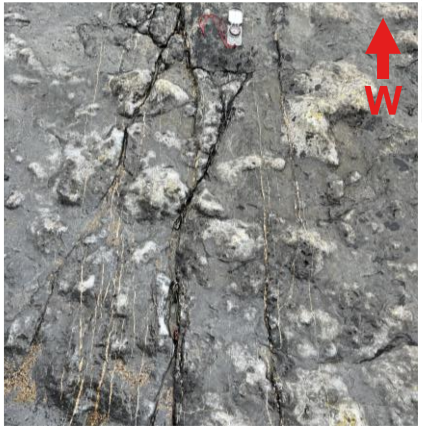


← A main zone of mineralisation along a fault, enclosing lenses of wall rock, with a network of smaller veins interconnecting and sub-parallel with the main mineralisation zone. BGS image P1079705 © UKRI 2024

BGS image P1079703 © UKRI 2024

3





BGS image P1079582 © UKRI 2024

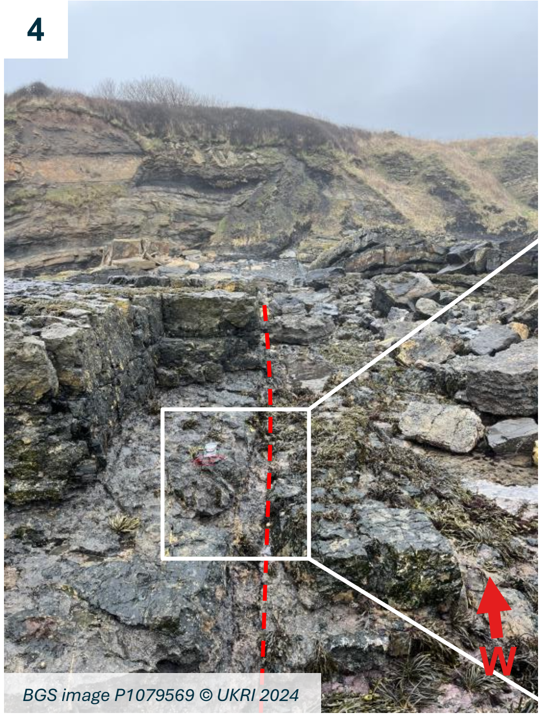
↑ A network of thin calcite veins, parallel or sub-parallel to the faults at A and B, located between the faults at A and B and ~ 1m north of the fault at A. BGS image P1079583 © UKRI 2024

Field Observations - Mineralisation

A - Howick Fault Zone

Photographs from Locations 4 and 5 on slide 7.

4



BGS image P1079569 © UKRI 2024

BGS image P1079564 © UKRI 2024

↑ Mineralisation along fault, parallel to sub-parallel to fault and stained red to green in colour. Jointing in the rock mass at this location is roughly parallel and orthogonal to the fault – mineralisation splays into orthogonal joints where they intersect the fault. Later, thin veins, which are short in length cut the mineralisation

5

← Several zones of fracturing and mineralisation, oriented approximately orthogonal (trending ~N-S) to the main faults cut the block south of the fault in D. Aerial imagery courtesy of Channel Coastal Observatory. Open Government License

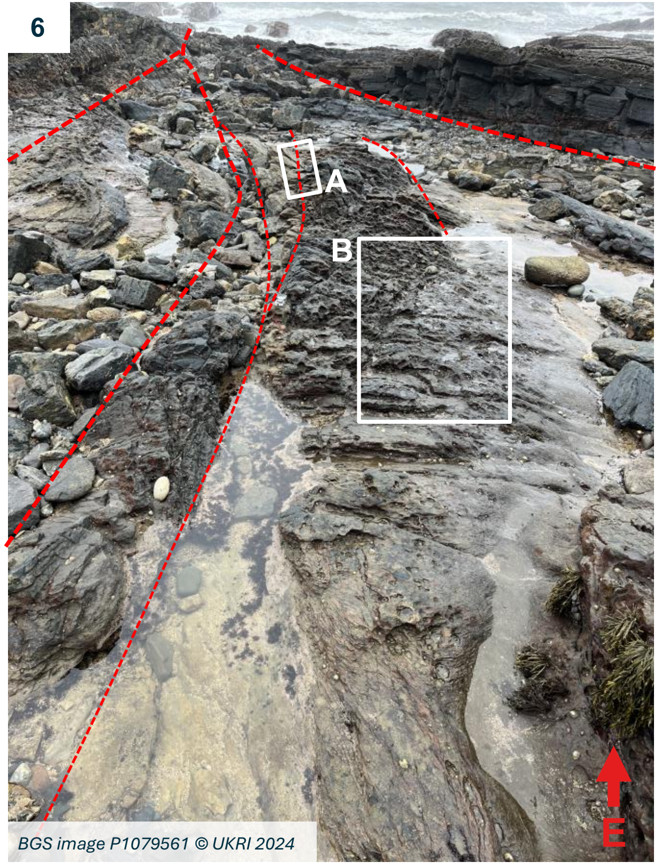
↓ The zone pictured below is ~ 1 m wide. Both the east and west walls of the zone are plastered with mineralisation. Within the zone, fractures are mostly oriented sub-parallel to the walls of the zone. Mineralisation along the fractures is common.

BGS image P1079565 and P1079566 © UKRI 2024

Field Observations – Fault Lense

A - Howick Fault Zone

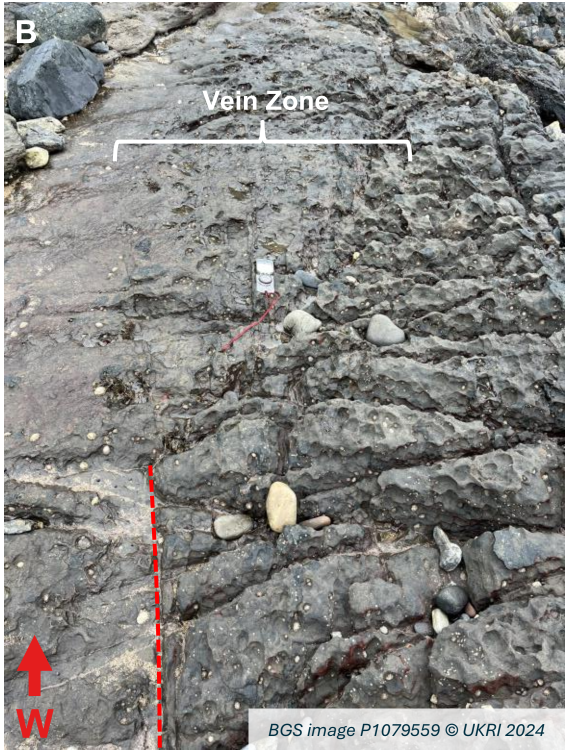
Photographs from Location 6 and 5 on slide 7.



← Lense of weakly deformed rock between two faults, which is cut by a number of minor faults, and veins.

↑ Minor faults splaying from each other (white dashed lines), separating a sandstone unit from a mudstone unit. The mudstone appears dragged into the faults a stringers.

→ Termination of a minor fault (red dashed line), characterised by thin veins. The deformation is spread out into a zone of over-stepping veins which can be seen where they weather positive to the rock mass.



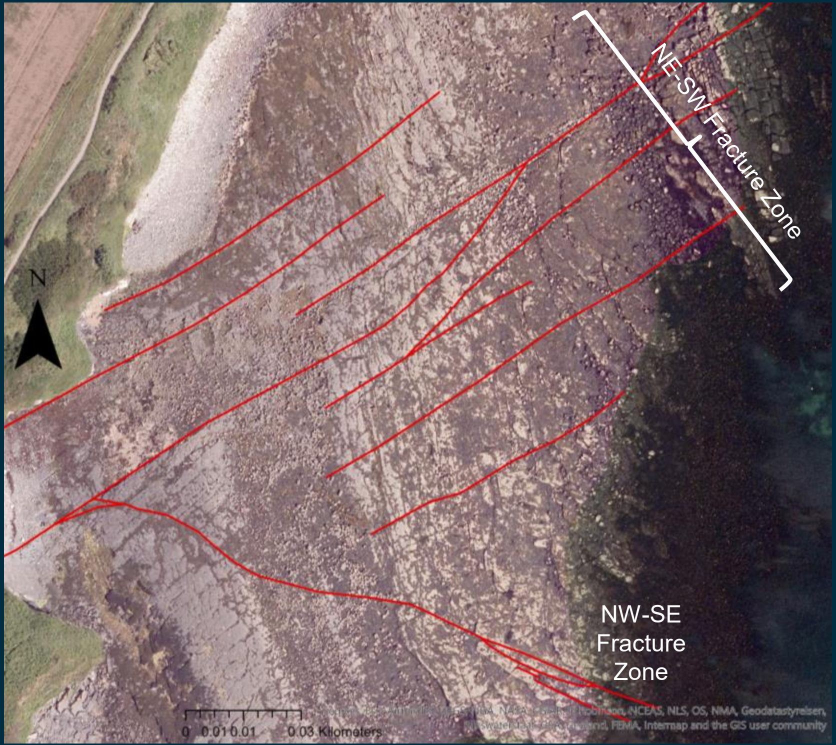
Field Observations – Plan View

Location B on slide 6.

↑ Distributed zone of fracturing cutting the Alston Formation on the wave-cut platform. The majority of the fractures trend ~ 060 and are parallel to the dominant joint trend in this area. The fractures are distinct from the joints in that they are through-going over 100-250, and cut multiple beds.

South of the NE-SW trending fracture zone, a ~ NW-SE trending fracture zone cuts the wave-cut platform, and connects with the NE-SW trending fracture zone in the west.

B – Fracture Zone



↑ The main fracture trends are highlighted with red lines. Image courtesy of Channel Coastal Observatory. Open Government License.

Field Observations – Plan View

Location C on slide 6.

The minor fault zone consists of two ENE-WSW trending faults that are connected by shorter NNE-SSW and E-W trending cross faults. The southern fault exhibits a relay zone.

A dolerite dyke (associated with the intrusion of the Whin Sill) occurs along the northern fault. De Paola et al. (2005) observe deflection of NE trending faults and fractures as they approach the dyke, suggesting faulting was syn- or post-intrusion of the dyke.

BGS image P1079738 © UKRI 2024

C – Minor Fault Zone

Aerial imagery courtesy of National Network of Regional Coastal Monitoring Programme © 2026 NNRCMP

Field Observations – Fold Trends

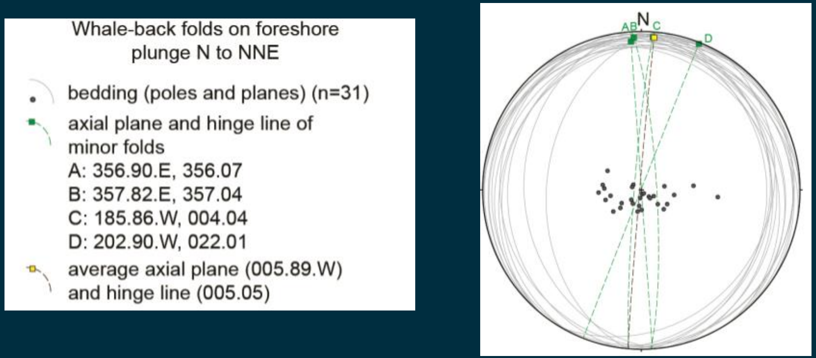
Location D on slide 6.

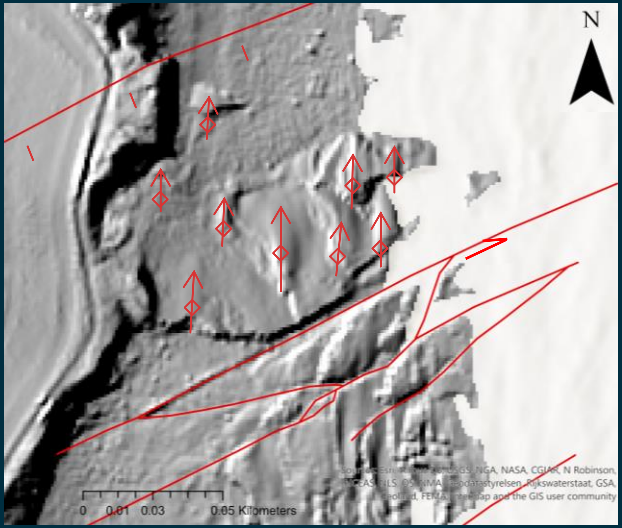
North-plunging whaleback folds affect the inter-bedded limestones and siltstones of the Four Fathom Limestone Member, at the top of the Aston Formation, between the NE-SW trending minor fault zone and the Cullernose Fault.

The fold axes are oriented obliquely (c.45°) to the NE-SW trending Cullernose Fault and minor fault zone, as well as minor NW-SE trending faults that cut the Whin Sill. Notably the fold axes are orthogonal to the E-W trending Howick Fault Zone. The fold orientation suggests an E-W directed compression.

The folding was observed locally between the two fault zones, but it is unclear whether the folds are the result of oblique transtension or related to emplacement of the Whin Sill.

D - Whale-Back Folds



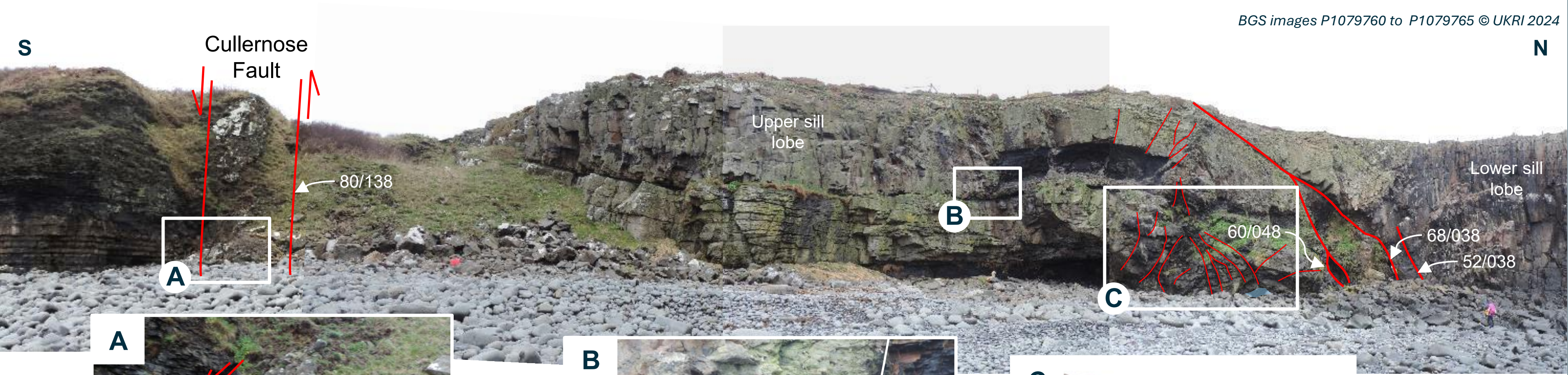


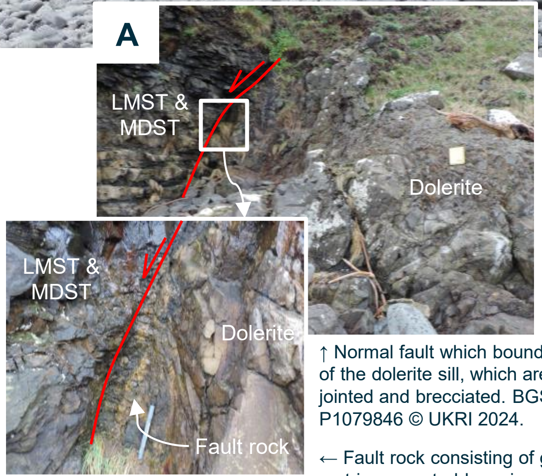
Field Observations – Cliff Section

Location E on slide 6.

E - Cullernose Fault

BGS images P1079760 to P1079765 © UKRI 2024

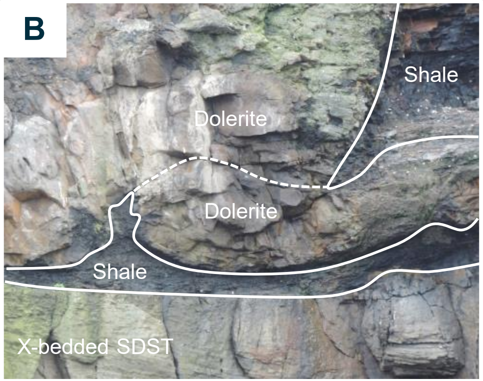




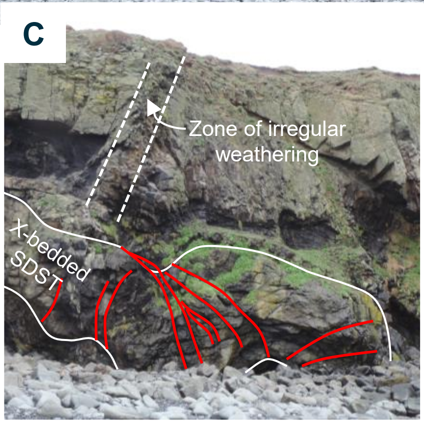
BGS image P1079854 © UKRI 2024

↑ Normal fault which bounds lenses of the dolerite sill, which are heavily jointed and brecciated. BGS image P1079846 © UKRI 2024.

← Fault rock consisting of gouge and matrix-supported breccia.



↑ Linking point (breached relay) between two sill lobes. BGS image P1079778 © UKRI 2024.



← Thick-bedded, cross-bedded sandstone, folded and fractured. The fractures accommodate small amounts of slip (cm-scale). BGS image P1079775 © UKRI 2024.

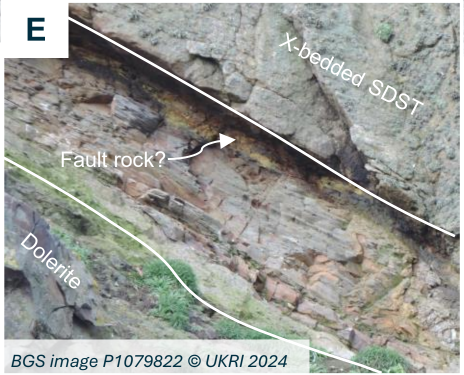
Field Observations – Cliff Section

Location E on slide 6.

E - Cullernose Fault

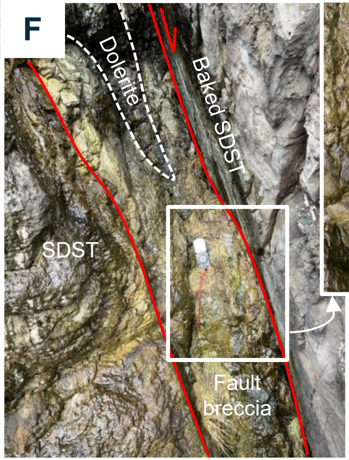
BGS images P1079760 to P1079765 © UKRI 2024

← Approximately triangular shape zone between the dolerite dyke and the sandstone. It is comprised of fault gouged and matric-supported breccia. Upwards the fault juxtaposes dolerite against dolerite and the width of the fault zone significantly reduces to a few centimetres. BGS image P1079414 © UKRI 2024.



BGS image P1079822 © UKRI 2024

↑ The contact between the cross-bedded sandstone and dolerite sill is not accessible. Zoomed in photos indicate a zone of laminated/thinly-bedded rock between the two, with a zone of breccia or gouge.



BGS image P1079644 © UKRI 2024

BGS image P1079641 © UKRI 2024

← Steeply inclined fault offsetting baked sandstone (next to the sill margin). The narrow fault zone is composed of a number of elongated fault lenses composed of clast-supported breccia and small amounts of gouge. In the top of the photo, a lense of the dolerite sill has been dragged down into the fault during slip.

Field Observations – Interpretation

Location E on slide 6.

E - Cullernose Fault

- The Whin Sill has previously been interpreted to exploit the Howick fault zone De Paola et al. (2005). At Cullernose Point the sill is cut by the Cullernose fault and associated faults. These relationships suggest that faulting in this area occurred before, during, and after sill emplacement and cooling. Further detailed work involving dating of fault rock and mineral fill may shed light on the timing relationships of faulting and sill emplacement.

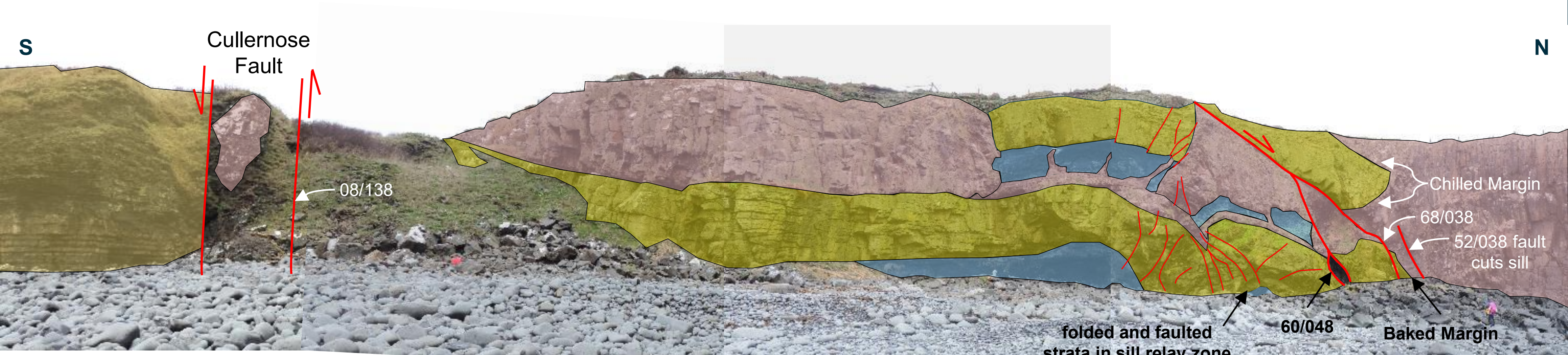
- At Cullernose Point the Whin Sill comprises two vertically offset lobes, connected via a breached relay (broken bridge). Xenoliths of country rock occur in the relay zone, which have baked margins against the sill. It is interpreted that the folding and minor faulting in the sandstone below the upper lobe is related to sill emplacement and linking of the lobes. This relay zone within the sill has been preferentially exploited by later faulting producing a complex fracture network in this location.

Dolerite (Whin Sill)

Mudstones/Shales

Cross-bedded Sandstones

Interbedded limestones & mudstones

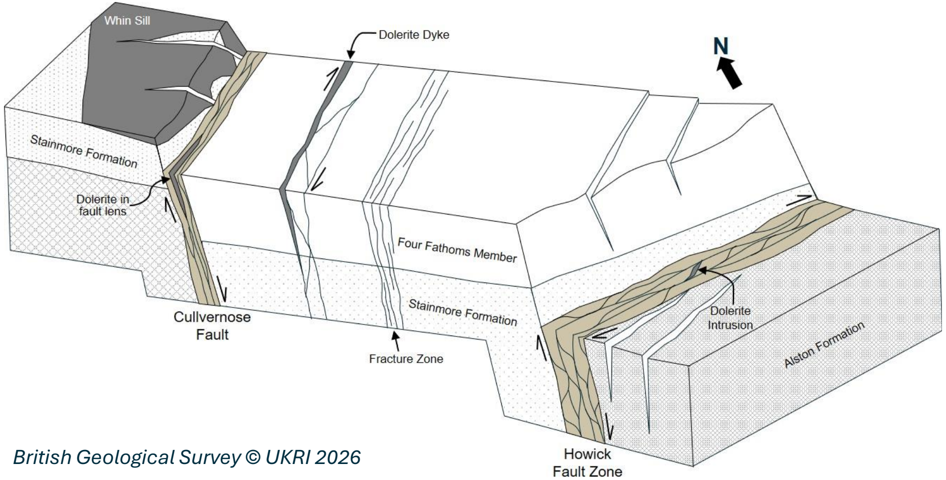


BGS images P1079760 to P1079765 © UKRI 2024

Local Interpretation

Multiple stages of deformation;

- Stage I: Normal faulting along the E-W trending Howick fault zone accommodated c.200 m vertical displacement across the Howick Fault during the Lower Carboniferous; juxtaposing the older Stainmore Formation in the footwall (north) against the younger Alston Formation in the hangingwall (south).
- Stage II: Normal-dextral oblique-slip or dextral strike-slip faulting syn-emplacement of the Whin Sill and associated dykes, which intruded the Howick Fault Zone and the minor fault zone (C) during the latest Carboniferous to earliest Permian.
- Stage III: Later normal or dextral-normal faulting accommodating tens of metres of displacement on the Cullernose Fault (likely Permian and younger).



Regional Interpretation

The stages of deformation observed at the Howick site reflect the multiple pulses of deformation thought to have affected the wider Northumberland Basin (Collier, 1989):

- Late Devonian – Early Carboniferous N-S to NNW-SSE extension associated with rifting of the Variscan foreland which produced ENE-WSW trending normal listric faults.
- Latest Carboniferous – Earliest Devonian emplacement of the Whin Sill Complex.
- Permian – Mesozoic NE-SW extension related to the collapse of the Variscan Orogeny which imposed a dextral-transtensional regime on inherited Variscan Faults.

Observations from the Howick Site may suggest emplacement of the Whin Sill Complex was contemporaneous with dextral transtensional deformation.

Glossary (Gillespie et al., 2011)

Term	Definition
bedding	layering that formed during depositional processes and is sometimes preserved in metamorphic rocks, particularly in areas of low strain. Individual layers are typical made-up of contrasting grain sizes.
cataclasis	rock deformation achieved through the formation of fractures and rotation of constituent crystals, grains, or aggregates without chemical reconstitution
cataclasite	fault-rock that is cohesive with a poorly developed or absent schistosity, or which is incohesive, characterised by generally angular porphyroclasts and lithic fragments in a finer-grained matrix of similar composition; generally no preferred orientation of grains or individual fragments is present as a result of the deformation, but fractures may have a preferred orientation; a foliation is not generated unless the fragments are drawn out or new minerals grow during the deformation; plastic deformation may be present but is always subordinate to some combination of fracturing, rotation, and frictional sliding of particles; cf. fault-breccia, fault-gouge, protobreccia, protocataclasite, mesocataclasite, and ultracataclasite
cataclastic	texture produced by cataclasis, characterised by fractures, rotation of constituent crystals, grains, or aggregates
damage zone	a zone of elevated fracture frequency around a fault
discontinuity	a feature marking a change in the continuity of a material at the scale of interest or observation; also, the generic term for all such features
fault	a fracture formed by, or incorporating, shearing displacement, along which there is discernible displacement parallel to the bounding surfaces at the scale of observation
fault-breccia	cataclasite, of which more than 30% consists of visible wallrock clasts, the remainder being dominated by very fine authigenic minerals (e.g. clay and Fe/Mn oxide/oxyhydroxide); cf. fault-gouge

Term	Definition
fracture	a deformation-break characterised by a discontinuous change in strength and/or stiffness, such that there is a stepwise change in the displacement distribution across it; the volume of deformed material associated with fractures (not including filling) typically has negligible thickness at the scale of observation (hence their surfaces are perceived to be sharply defined); such features typically consist of two opposing surfaces in contact or close proximity
joint	a fracture formed by opening displacement, synonymous with crack
mesocataclasite	cataclasite in which the matrix forms more than 50% and less than 90% of the rock volume
protobreccia	cataclasite in which the matrix forms less than 10% of the rock volume
protocataclasite	cataclasite in which the matrix forms between 10 and 50% of the rock volume
relay zone	a zone in between two related fault segments, where displacement is transferred (‘relayed’) from one fault segment to another; typically marked by a series of minor faults oblique to the main fault segments
slickenline	lineation on a slickenside, defined by grooves, ridges or striations, generally parallel to the direction of the slip vector
slickenside	polished fault surface (with or without lineations)
splay	a fault developed as an offshoot from another fault
ultracataclasite	cataclasite in which the matrix forms more than 90% of the rock volume

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