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# UK Structure Site Report: Seaton Sluice (Whitley Bay)

British Geological Survey

BGS REPORT NUMBER: OR/25/025

## Abstract

Understanding the architecture and connectivity of faults and joints through mechanically layered stratigraphy is important for understanding controls on groundwater flow and fluid compartmentalization. The Seaton Sluice site provides an excellent cross-section through three fault zones associated with the regional ENE-WSW trending 90-Fathom Fault. The faults transect an interbedded sequence of Carboniferous strata comprising sandstones, shales, and coals in the Northumberland Basin. Layer thickness and lithology control joint spacing and fault attitude, and shale smears along fault planes may create local barriers to cross-fault fluid flow in the subsurface. This work is particularly applicable to groundwater studies in the Northumberland Basin.

## 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 through a mechanically layered sedimentary sequence, using an example from Seaton Sluice, Whitley Bay.  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 vertical coastal cliff sections. A detailed study of the Seaton Sluice fault network and the lateral fault connectivity was conducted by Andrews (2020).



*Bibliographical reference*

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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 P1078922 © UKRI 2024. See also slide 6.

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 Seaton Sluice site area is located on the Northumberland coastline approximately 4 km north of Whitley Bay and 13 km northeast of Newcastle, within the Northumberland Basin (also referred to as the Northumberland Trough).

The Northumberland Basin represents an early Carboniferous depocentre in the Variscan Orogenic foreland region of Northern Britain. The basin forms one in a series of ENE-WSW trending fault-bound troughs (with intervening structural highs) that together make up the Northern Pennine Basin (Figure 1). The Northumberland Basin overlies the Iapetus suture zone, which was reactivated as an extensional structure during N-S to NNW-SSE mid-late Carboniferous extension, the Stublick-90 Fathom Fault array, which bound the south of the Northumberland, basin are thought to represent synthetic normal faults which decol into the underlying shear zone (Leeder, 1975; Chadwick et al., 1995).

The Northumberland Basin is bound to the north by a series of faults and the Cheviot block and to the south by the Stublick-90 Fathom Fault system and Alston Block (Howell et al., 2022) (Figure 1). The basin acted as significant depocentre for sediment accumulation during the Carboniferous, with up to 4000 m thick sediment package at the Stublick-90 Fathom Fault, which thins to an approximately 500 m thick package above the Cheviot and Alston Blocks, suggesting these were structural highs during deposition (De Paola et al., 2005 and references therein).

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 (WDD) across the Cheviot Block and an extension-dominated domain (EDD) in the Northumberland trough.

The Seaton Sluice site is located ~8 km north of the basin bounding 90 Fathom Fault and provides an excellent cross-section through three fault zones associated with the major fault zone. The fault zones transect an interbedded sequence of Carboniferous strata providing an excellent opportunity to demonstrate fault geometry in a mechanically layered sequence.

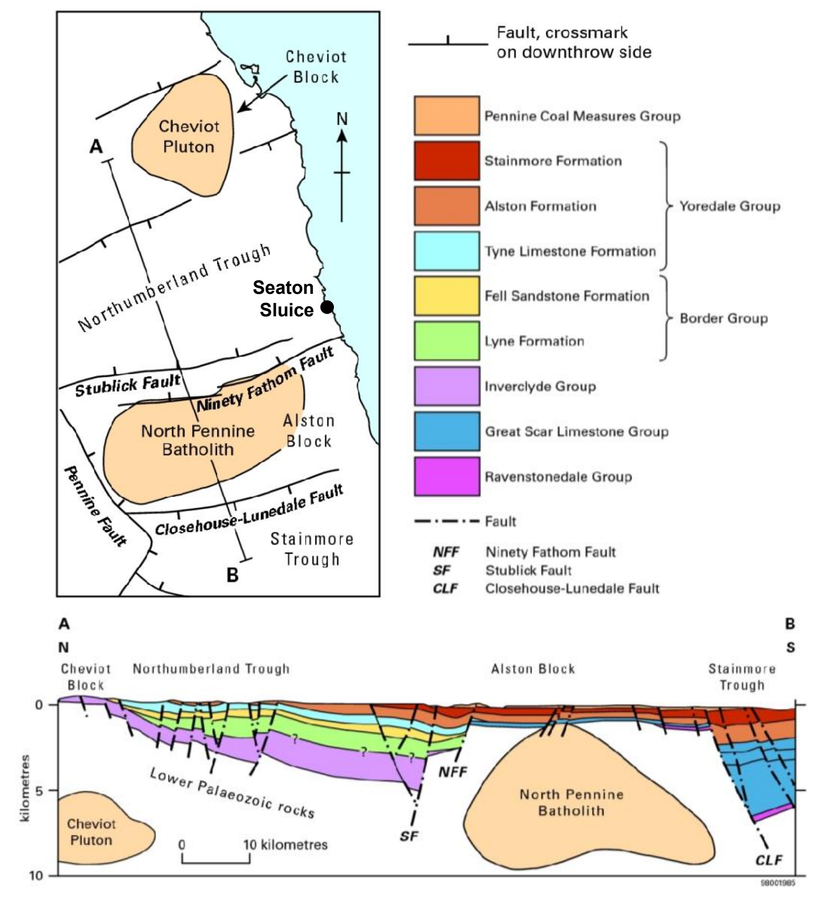



*Figure 1. (a) Schematic map and cross-section showing the block and basin structure of the Northern Pennine Basin. Figure from Stone et al. (2010). British Geological Survey © UKRI 2010.*

# Seaton Sluice

The site area is located between Seaton Sluice and Whitley Bay along the Northumberland Coastline. The study focussed on exposures along the coastal foreshore and cliff sections between Crag Point and St Mary's Lighthouse (Figure 2).

Several fault zones are exposed in the cliff sections here: the E-W trending Crag Point Fault Zone (CPFZ), and the NE-SW trending Hartley Steps Fault Zone (HSFZ) and St Mary's Bay Fault Zone (SMBFZ). Andrews (2020) interprets the HSFZ and SMBFZ to be linked by an ESE-WNW Hartley Point Fault Zone (HPFZ).

Cliff sections at the site provide an excellent opportunity to observe fault and fracture geometries within an interlayered package of lithologies with contrasting physical and mechanical properties.

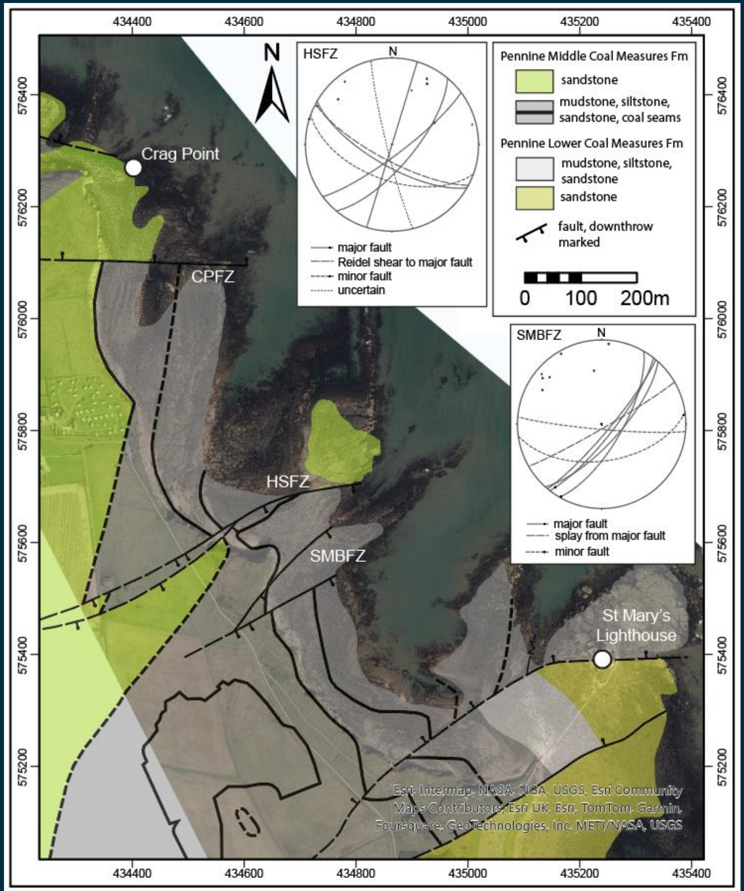



*Figure 2. Seaton Sluice field area showing the Crag Point Fault Zone (CPFZ), Hartley Steps Fault Zone (HSFZ), and St Mary's Bay Fault Zone (SMBFZ) as mapped on the current British Geological survey 1:10 000 bedrock geology (BGS © UKRI). Lower hemisphere equal area stereographic projections of collected Fault data during this study for the HSFZ and SMBFZ, plotted as poles and planes with rake. Aerial imagery courtesy of National Network of Regional Coastal Monitoring Programme © 2026 NNRCMP.*

*Map produced in QGIS: ESRI, Intermap, NASA, NGA, USGS, Esri Community Maps for Contributors, Esri UK, Esri, TomTom, Garmin, Foursquare, GeoTechnologies, Inc, METI/NASA, USGS*

# Seaton Sluice

The stratigraphy at Seaton Sluice comprises a laterally continuous interbedded package of shallowly dipping mudstones, siltstones, sandstone and coal of the Carboniferous Pennine Middle Coal Measures Formation (Duckmantian Substage — Bolsovian Substage of the Westphalian Stage) (Figure 3). The sandstone packages are a minimum of 2 m thickness and comprise beds of approximately 5 to 20 cm thickness. Mudstone and coal units are friable.

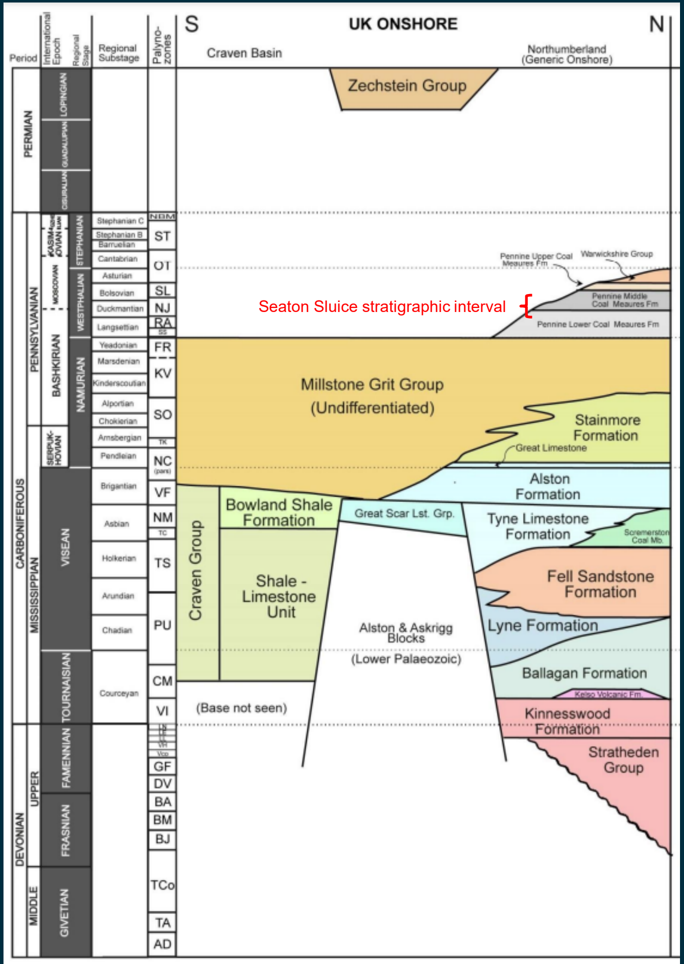



*Figure 3. Schematic north – south cross-sections showing the Carboniferous and Devonian strata of northern England. From Kearsey et al. (2015). British Geological Survey © UKRI 2015.*

# Crag Point Fault Zone

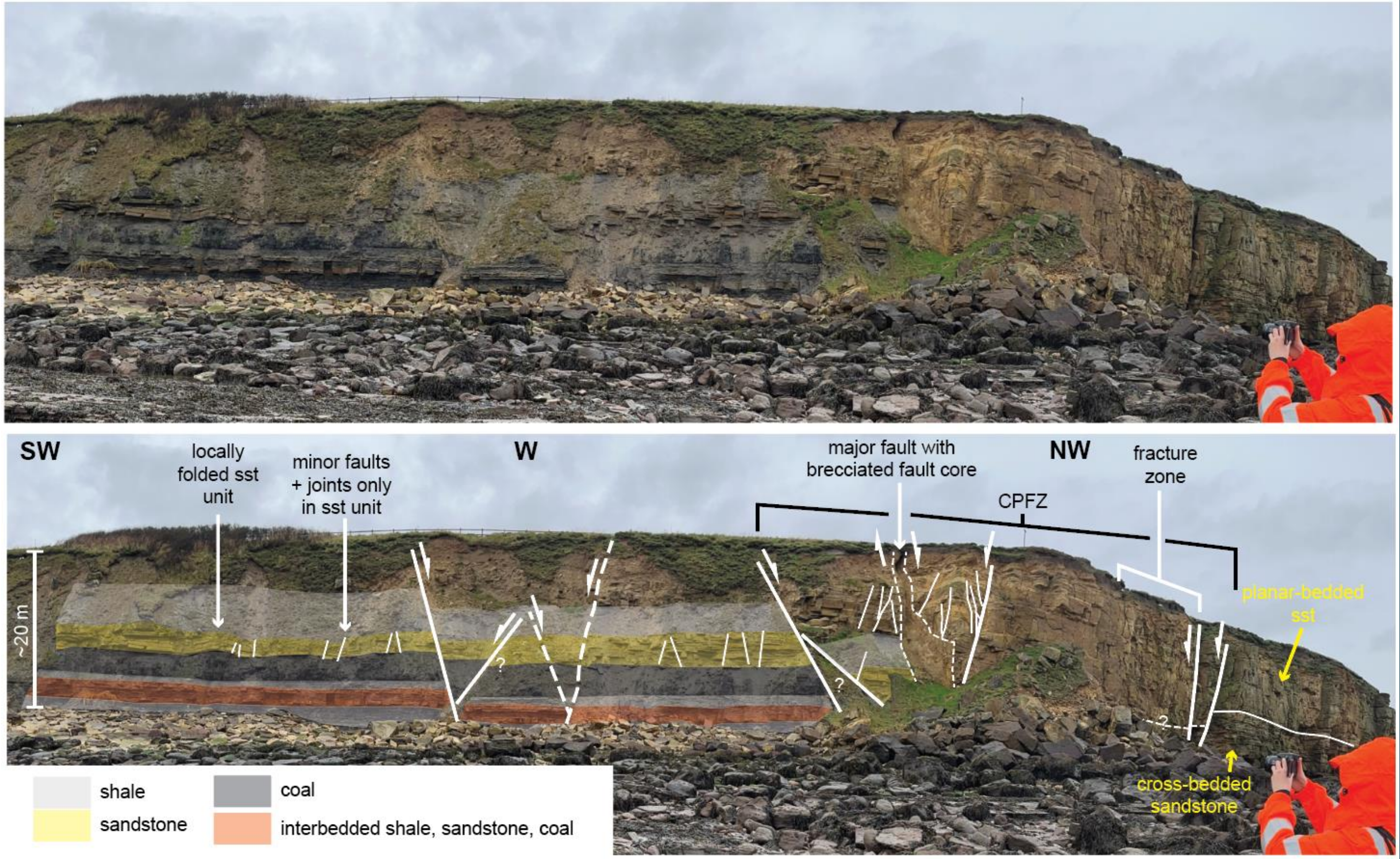



*Figure 4. Overview photo and interpreted photo of the Craig Point Fault Zone (CPFZ). BGS image P1078922 © UKRI 2024.*

The Crag Point Fault Zone (CPFZ) comprises a series of E-W to ESE-WSW trending fault strands that make up an ~80 m wide fault zone (Figure 4). The main fault juxtaposes a thick sandstone package against interbedded sandstone, shale, and coal units. Andrews (2020) found that the main fault strands in the CPFZ display low-angle strike-slip lineations, while a subsidiary fault set displays dip-slip lineations. Jones and Deerman (1967) estimate a cumulative throw of 200 m across the CPFZ.

Minor conjugate faults were observed in the hangingwall cliff section immediately south of the main fault zone. These faults cut the sandstone units and terminate in the over-and underlying shale and coal units.

The foreshore exposure could not be accessed during the site visit due to the tide and boulder cover. Observations were made at a distance.

# Hartley Steps Fault Zone

The Hartley Steps Fault Zone (HSFZ) comprises a series of NE-SW to ENE-WSW trending fault strands that make up an ~60 m wide fault zone (Figure 5). Major faults accommodate dextral strike-slip motion. Subsidiary fault sets display a range of dips and form arrays of synthetic and antithetic faults that accommodate an overall normal displacement with a general southwards downthrow. Fault attitudes vary through the cliff section, with steeper dips in the sandstone units and shallower dips in shale and coal.

Overall, the HSFZ accommodates a cumulative throw of 17 m which is distributed across the zone where individual fault strands may accommodate cm to m-scale throw (Færseth et al., 2007).

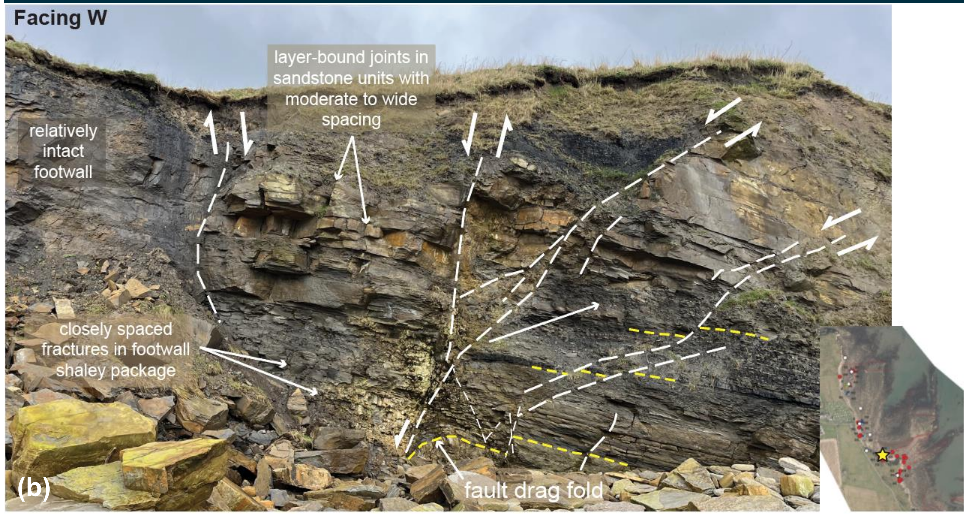




*Figure 5. (a) Panorama cliff section through the Hartley Steps Fault Zone. Zoom in photo of a subsidiary fault array, showing varying fault plane dips, fault-drag folding across the main fault plane, and joint spacing variability between different lithological units. BGS images P1079321 and P1079229 © UKRI 2024.*

# St Mary’s Bay Fault Zone

Major faults in the St Mary’s Bay Fault Zone trend NE-SW and transect all stratigraphic units observed (Figure 6). These faults are predominantly strike-slip (rakes of ~8° towards SW) with a minor dip-slip component (dcm scale throws). Faults tend to display downthrow to the south suggesting dextral-oblique slip.

Overall, the fault planes are undulating with steeper (near-vertical) dips in the sandstone, and inclined dips in the shale and coal units. Minor faults are unit-bound horst and graben sets with displacements on the cm to dcm scale. These faults cut the sandstone units and terminate in the overlying shale and coal units, causing minimal displacement of these units.

In vertical section, the fault zones tend to be wider within the shale and coal units, expressed as wide zones of extremely close to very close fractures. In sandstone units, faulting appears to be more localised forming discrete planes that envelop lenses of closely-spaced fractures and/or Riedel shears that are oblique to the main fault planes (b, d). Where faults terminate within the shale and coal units, deformation is accommodated as zone of local rotation of laminations between fault surfaces with minimal displacement.

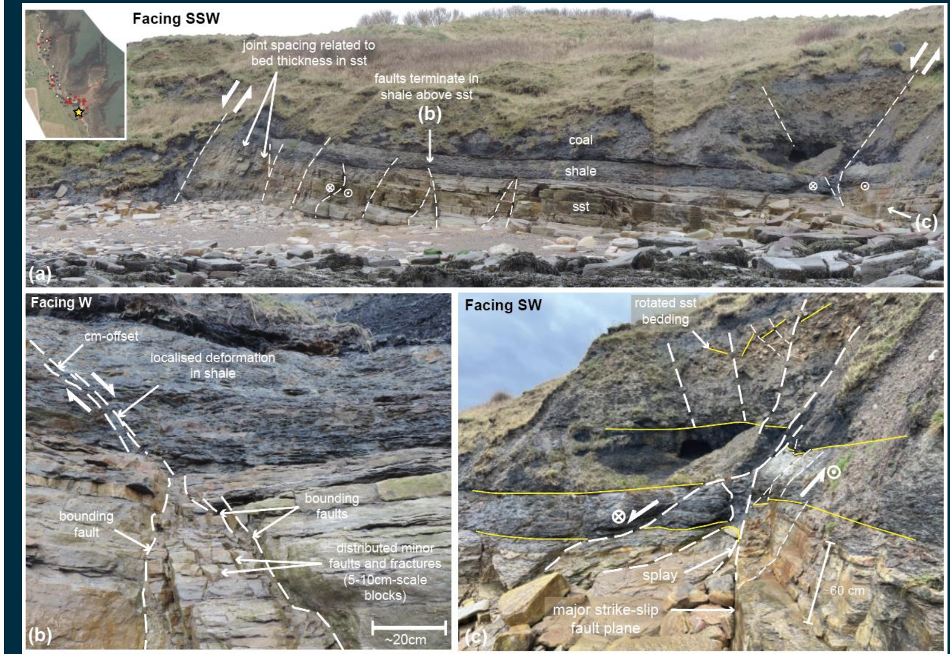


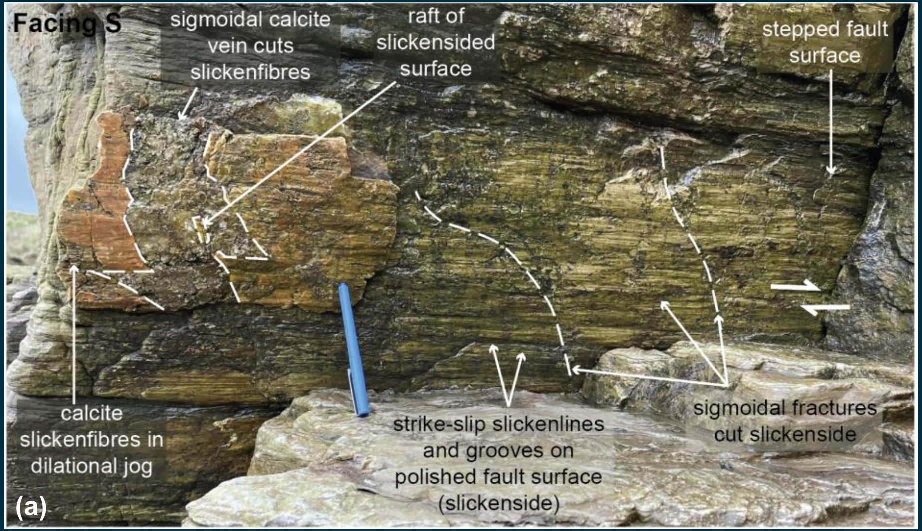

*Figure 6. St Mary’s May Fault Zone. (a) Overview of faulted section showing variable fault geometries and fault attitudes through mechanical stratigraphy. (b) localised deformation in shale unit above sandstone. (c) distributed deformation across shale and coal. BGS Images P1079256, P1079300, P1079085 © UKRI 2024.*

# Field Observations

Fault Surfaces & Shear-sense Indicators

Fault planes in sandstone units are commonly polished (slickensides) and occasionally iron-stained (heamatite and goethite). The shear sense can be interpreted from slickenlines and grooves, steps, calcite slickenfibres and sigmoidal fractures that cut the slickenside (Figure 7 a).

Shear sense is also indicated by apparent fault drag folds within fault zones (Figure 7b). Bedding and lamination are rotated within fault zones on the cm to metre-scale, the rotation is accommodated across a series of small synthetic faults with mm-cm scale displacement inferred to represent synthetic R-shears.



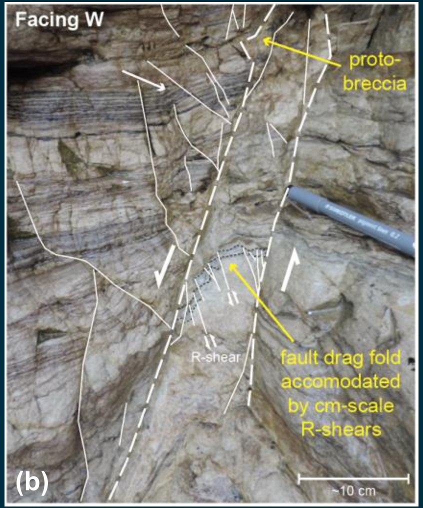




*Figure 7. Examples of fault surface structures and shear-sense indicators observed in the Seaton Sluice site area. (a) Polished fault surface (slickenside) with slickenlines, steps, slickenfibres, and sigmoidal fractures that cut the slickenline. The shear-sense indicators suggest a dextral strike-slip motion across this fault plane. (b) Fault-drag fold across a small (cm-scale) fault zone. The fold is comprised of multiple minor synthetic faults. The drag direction suggests a normal fault with downthrow to the south. Note the series of small antithetic faults in the footwall block adjacent to the fault zone. BGS images P1078965, P1079294 © UKRI 2024.*

# Field Observations

Fault Rock

A variety of fault rock types occur across the site at Whitley Bay (Figure 8).

Shale smears occur on fault planes as patches and are common where shale overlies sandstone and has been dragged into the fault plane (Figure 8a). Shale smears may also display slickenlines indicating the shear sense.

Lenses of unconsolidated fault gouge and fault breccia, as well as consolidated protobreccia and proto-cataclasite are common along fault planes (Figure 8b-c). Locally, lenses of vein-hosted protobreccia also occur associated with thin (~2 mm thick) veins (Figure 8d), however generally veining is rare in the Seaton Sluice site area.

Some fault-bound blocks contain short subvertical fractures that are oriented obliquely to the main fault planes, these are interpreted as Reidel shears (Figure 8e-f).

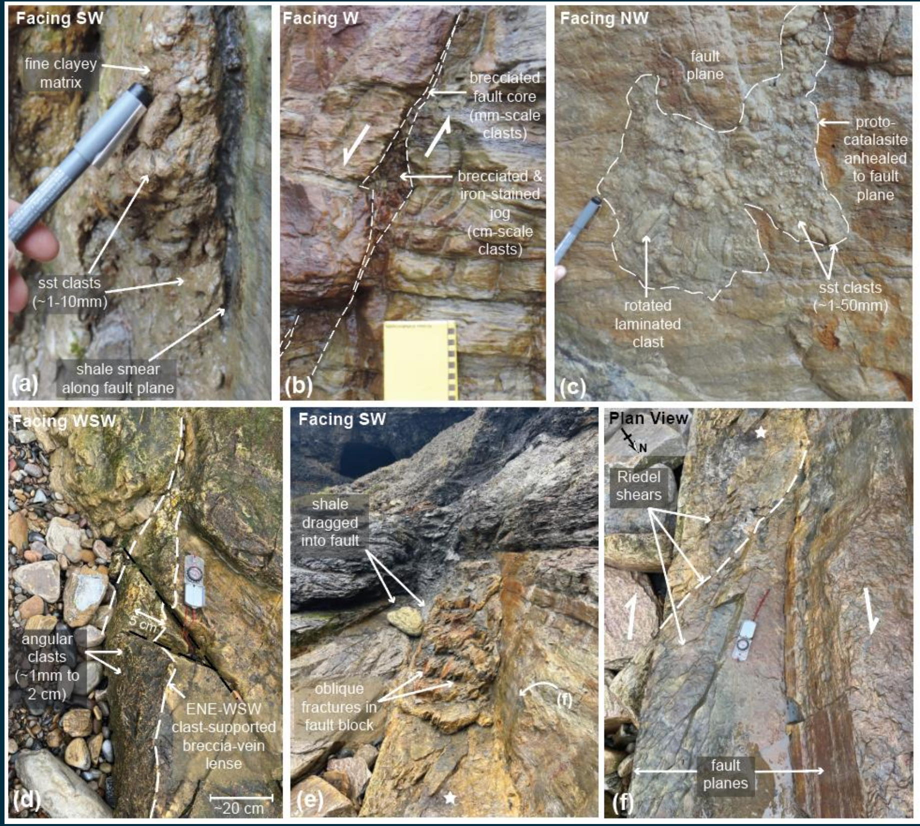



*Figure 8. Selection of fault rock observed across the Seaton Sluice site area. (a) Fault breccia (>30% clasts in a clayey matrix, unconsolidated, disaggregates between fingers). (b) Proto-breccia (crackle breccia, cf. Woodcock & Mort, 2008) within a jog between overlapping fault segments (cm-scale clasts with <10% matrix, consolidated). (c) Proto-cataclasite (chaotic breccia, cf .Woodcock & Mort, 2008) (mm-cm scale clasts surrounded by a fine matrix, consolidated). (d) Proto-breccia lense (crackle breccia, cf .Woodcock & Mort, 2008) with fine matrix. (e-f) oblique fractures and minor Riedel shears within a fault-bound block. The star indicates the same point in (e).*

*BGS images P1079309, P1079286, P1079310, P1079095, P1079084, P1079080 © UKRI 2024.*

# Field Observations

## Joint Orientation

Three key joint orientations occur in the Whitley Bay site: trending E-W, NW-SE, and NNE-SSW (Figure 9).

- E-W joints (including ENE-WSW and ESE-WNW trends) are systematic and occur across the site area. Major E-W joints have high to very high persistence (with lengths generally exceeding 10 and 20 m) and very wide to extremely wide spacings (3 – 15 m). Minor E-W joints have very low to medium persistence and moderate to wide spacing.
- NW-SE joints are systematic and occur predominantly around the Crag Point Fault Zone. This joint set has low to medium persistence (~5 – 10 m length), and wide spacing (~1 – 2 m). The NE-SW and E-W joint sets have a mutual relationship, and form parallelepiped joint-bound blocks with long axes that trend SSE-NNW.
- NNE-SSW to NE-SW joints are systematic and occur close to the Hartley Steps Fault Zone. This joint set has medium to high persistence and wide to very wide spacing. The NNE-SSW and E-W joint sets have a mutual relationship, and form parallelepiped joint-bound blocks with long axes that trend ENE-WSW.
- Minor non-systematic joints also occur, these tend to have low to very low persistence and terminate against the other joint sets.

## Joint Spacing

Joint spacing and height (in vertical section) varied by lithology and bed thickness.

- Coal and shale units are not jointed.
- Thicker sandstone beds have wider joint spacing than thinner sandstone beds or silty-sandy units.
- Many joints in sandstone beds appear to terminate at the bedding plane between the sandstone and underlying and overlying coal or shale units.

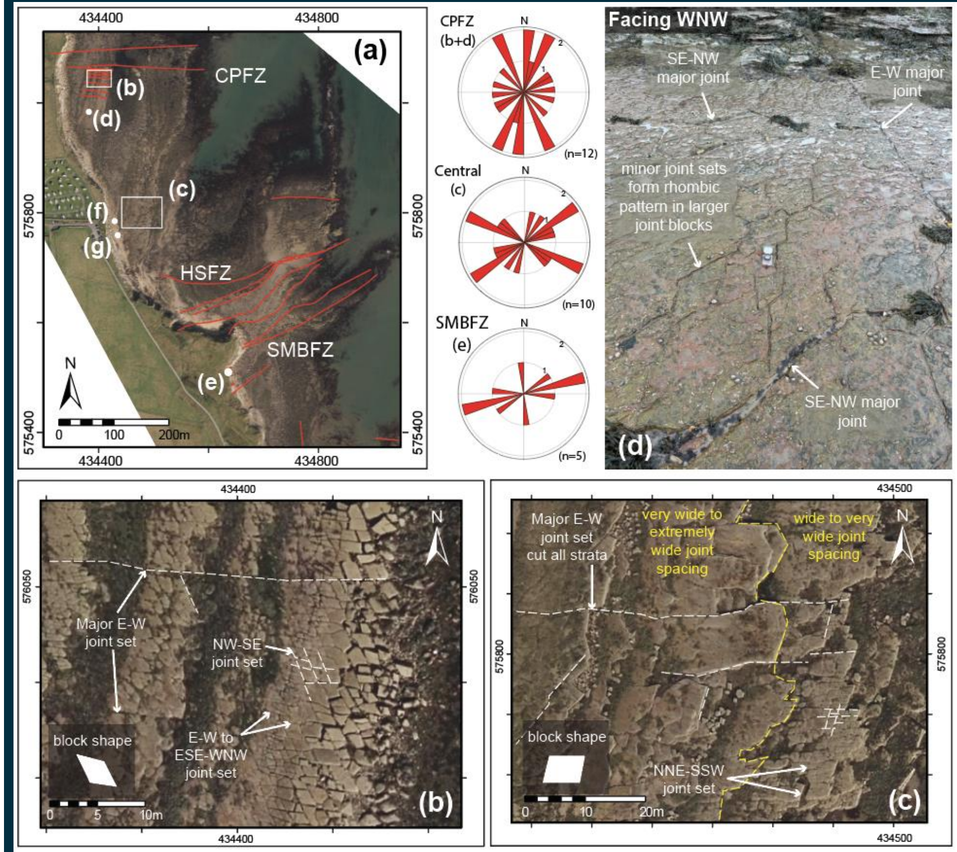



*Figure 9. Joint geometry across the Seaton Sluice site area. (a) Overview map showing the locations b-g. Lineaments identified from aerial imagery are red lines. Rose diagrams show joint orientation variation across the area. (b) Aerial Imagery showing the joint pattern within the Crag Point Fault Zone. (c) Aerial Imagery showing the joint pattern between the Crag Point Fault Zone and Hartley Steps Fault Zone. (d) Photograph of minor joint pattern close to the CPFZ. BGS Image P1079025 © UKRI 2024.*

*(a – c) contain Aerial imagery courtesy of National Network of Regional Coastal Monitoring Programme © 2026 NNRCMP*

# Field Observations

**Joints**

Iron-stained halos were noted around joints close to the fault zones and tend to weather proud of the outcrop surface (Figure 9 f-g). The halos have equal width either side of the joint plane and their width increased from 2 – 10 cm as distance to the fault zone increased. This may represent fault-related (or post-faulting) fluid flow through the open joint networks.

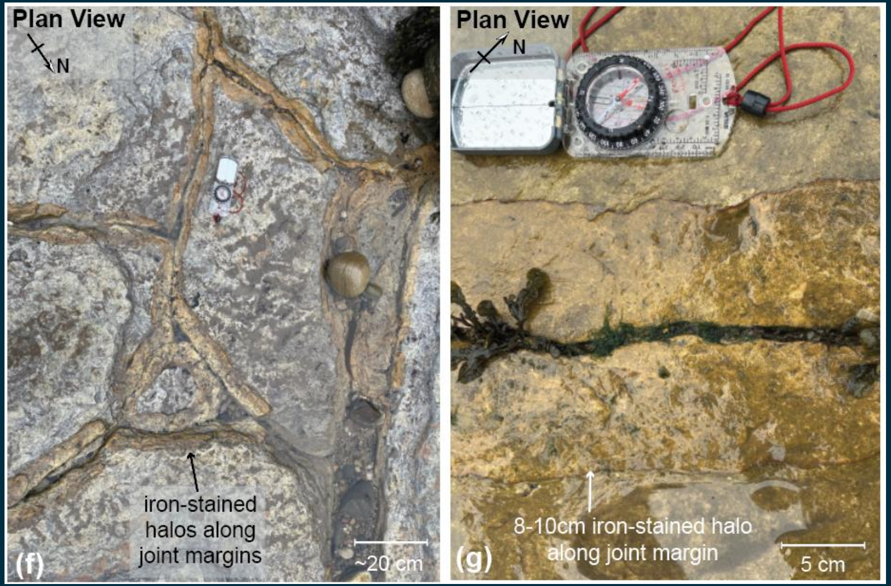



*Figure 9 Continued... (f) Photograph showing 2-5 cm iron-stained halos around multiple joint sets. (g) Photograph showing 8-10 cm iron-stained halos around a NNE-SSW joint. BGS image P1079032, P1079043 © UKRI 2024.*

# Conceptual Model

## Mechanical Stratigraphy

### Joints

Joint spacing and height (in vertical section) varies by lithology and bed thickness:

- Coal and shale units are not jointed.
- Thicker sandstone beds have wider joint spacing than thinner sandstone beds or silty-sandy units.
- Many joints in sandstone beds appear to terminate at the bedding plane between the sandstone and underlying and overlying coal or shale units.

The observed joint patterns create variably connected fracture networks (and potential fluid pathways) both laterally and vertically through stratigraphy (Figure 10).

### Faults

Fault dip and fault zone width varied with lithology (Figure 11):

- Fault planes have steeper (near-vertical) dips in sandstone units and inclined dips in the shale and coal units.
- Minor faults (cm-dcm displacement) are unit-bound horst and graben sets that cut the sandstone units and terminate in the overlying shale and coal units.
- Fault zones are wider in shale and coal units, expressed as zones of extremely close to very close fractures. In sandstone units, faulting appears to form discrete planes that envelop lenses of closely-spaced fractures and/or Riedel shears that are oblique to the main fault planes.
- Shale smears occur locally along fault planes, these may act as local impermeable barriers to cross-fault fluid flow. Understanding the distribution of shale smears along fault planes is therefore important to understanding fluid flow through mechanically layered sequences.

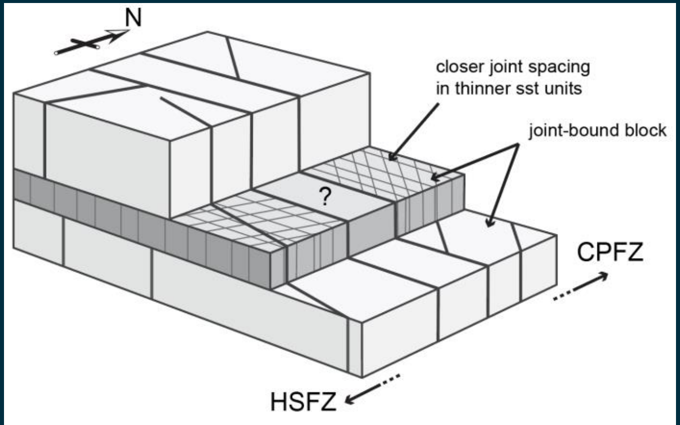



*Figure 10. Schematic diagram of joint geometry across the Seaton Sluice site area. British Geological Survey © UKRI 2025*

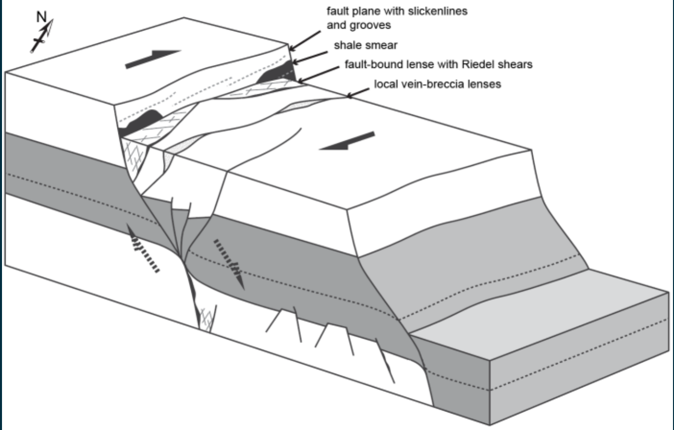



*Figure 11. Schematic diagram of the St Mary's Bay Fault Zone in the Seaton Sluice site area. British Geological Survey © UKRI 2025*

# Regional Context

The studied section at Seaton Sluice lies within the Northumberland Basin of the Pennine Basin. The Pennine Basin developed as a result of episodic N-S oriented extension and reactivation of pre-existing E-W oriented Acadian faults, in the foreland basin region of the Variscan orogen. Rifting began in the late Devonian-Tournaisian and continued into the Namurian (Woodcock and Strachan, 2012). This created a series of E-W trending normal faults with horst-graben geometries in the Laurentian basement, the basins were progressively infilled with Carboniferous strata. A period of inversion has long been proposed to occur during the late Carboniferous (late Brigantian Stage). De Paola et al. (2005) suggest an alternative model whereby the Northumberland Basin fault systems represent late Carboniferous partitioned dextral transtension.

The studied faults are located ~8 km north of the basin bounding 90 Fathom Fault. The CPFZ represents one of the major E-W faults, displaying dextral strike-slip motion with a normal slip component (Andrews, 2020; Jones and Deerman, 1967). The HBFZ and SMBFZ are NE-SW trending dextral to dextral-oblique slip faults, which are inferred to represent synthetic (P-Shears) to the CPFZ, part of an overall dextral fault system (Andrews, 2020), suggesting the fault system forms a connected fault and fracture network at depth. All three fault zones cross-cut Westphalian strata, indicating late Carboniferous dextral strike-slip movement across these faults. This contrasts with the findings of De Paola et al (2005), who mapped this area as predominantly normal faults reflecting a zone of extension-dominated transtension. Sub-horizontal slickenlines on many of the major fault surfaces indicate a significant strike-slip component. This suggests that the Northumberland Basin may also represent a zone of homogenous wrench-dominated trenstension with a horizontal and NNE-SSW oriented $\sigma_3$ and ESE-WNW oriented $\sigma_1$; alternatively, this fault system may reflect additional strain partitioning across the basin, particularly in close proximity to the basin-bounding faults.

# 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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