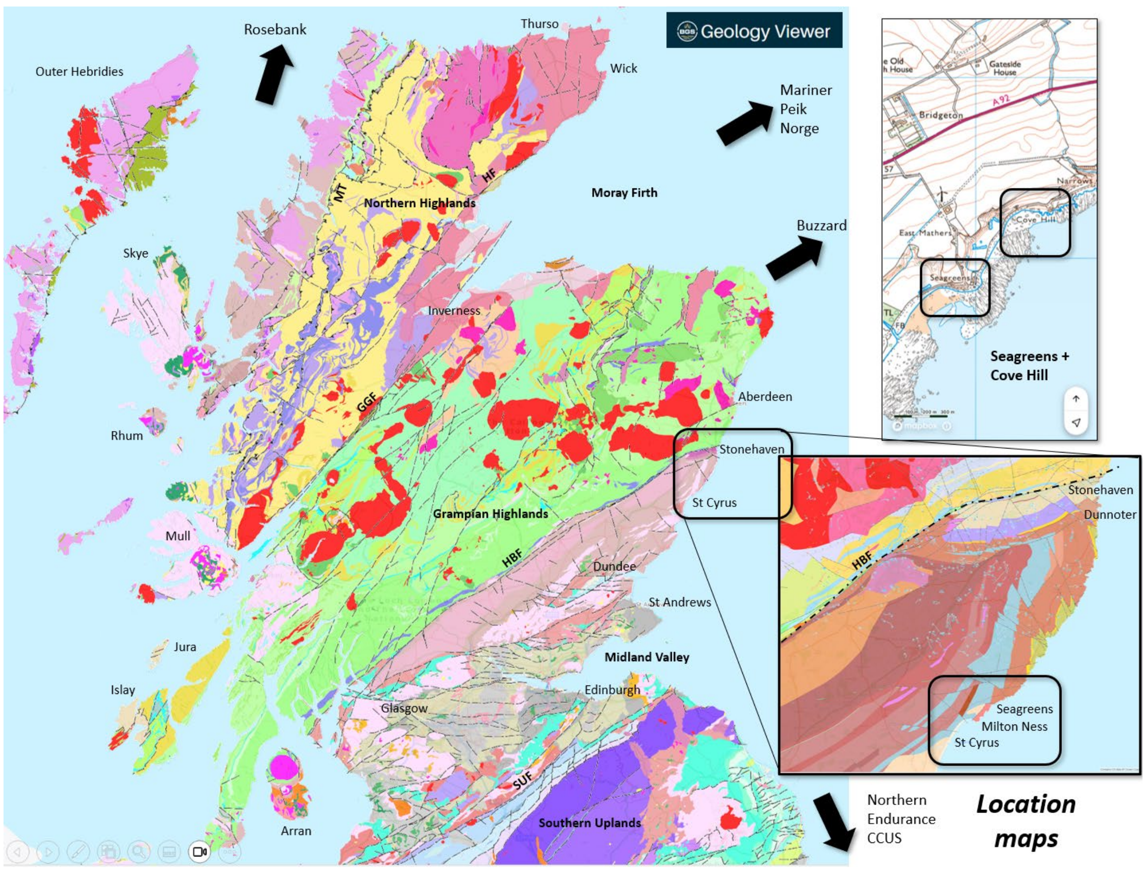
equinor

# Well Services Field Day

# Seagreens and Cove Hill, SE Aberdeenshire

## May 14th 2024




***Location maps***

# 1 Introduction, regional setting, links to offshore UKCS and NCS fields and reservoirs

The Seagreens and Cove Hill sections we will visit expose Lower and Upper Devonian-Early Carboniferous intervals within the Midland Valley Terrain of Scotland. The Lower Devonian is locally termed the "Lower Old Red Sandstone" (LORS), whilst the Upper Devonian-Early Carboniferous is termed the "Upper Old Red Sandstone" (UORS). The "New Red Sandstone" is the UK Triassic, and is not exposed in this part of Scotland, but is facies comparable to the "Old Red Sandstone". In terms of a basin setting, the Midland Valley formed a low lying rift environment during the Devonian and Carboniferous bounded by high standing older Caledonian basement blocks to the north (Grampian Highlands) and south (Southern Uplands) respectively. Analogy in terms of structural setting, facies and climate can be drawn to the present day Basin and Range and Death Valley areas of western USA.

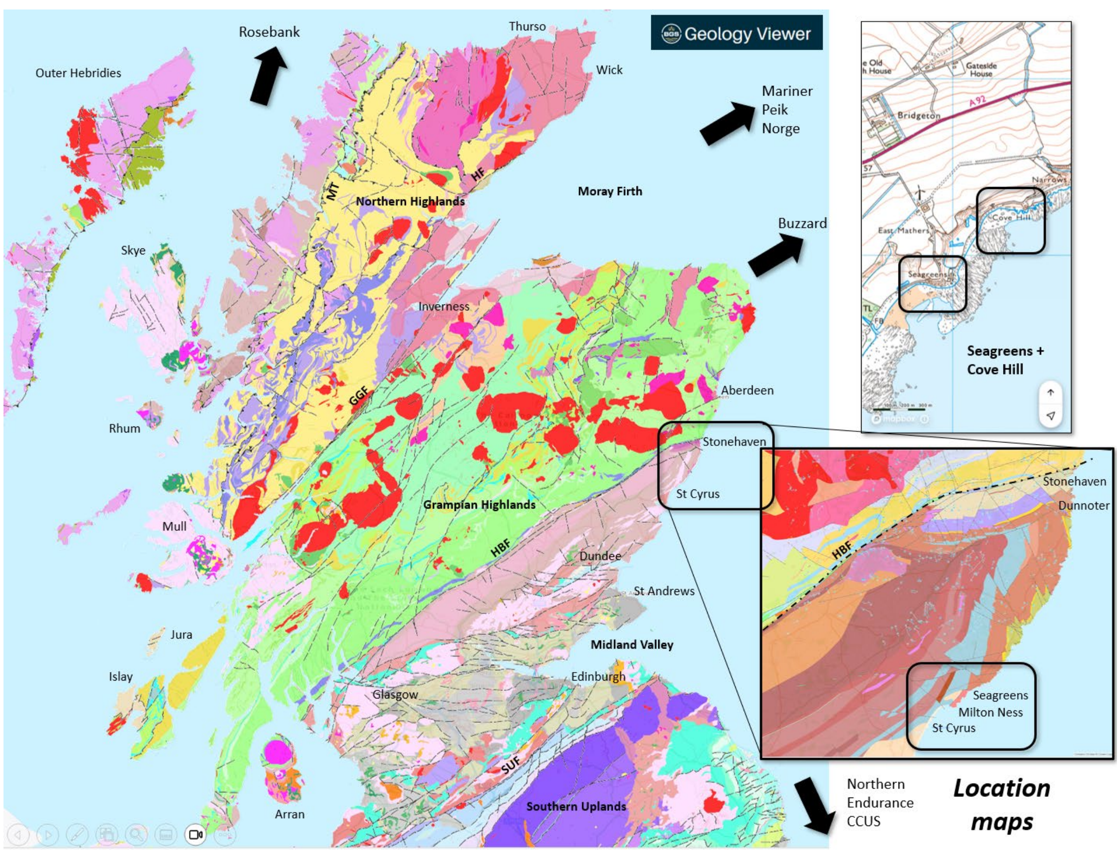
The Lower Devonian is characterised by a thick succession of interbedded igneous and alluvial-fluvial to lacustrine rocks deposited in an overall semi-arid setting. The igneous units include extensive andesitic lava flows and localized volcanic centres, with lavas erupted into both subaerial and locally subaqueous settings. These will be examined in more detail at the St Cyrus stops and at the northern end of the Cove Hill section. The alluvial-fluvial intervals are characterised by conglomerate-sandstone ephemeral alluvial to braid plain river systems. Palaeocurrents indicate an overall NE to SW palaeoflow for the fluvial systems, with a likely provenance at least in part from Scandinavia. The Lower Devonian was folded, uplifted and partly eroded prior to deposition of the overlying Upper Devonian-Lower Carboniferous UORS. The Upper Devonian-Lower Devonian is devoid of volcanics and is characterised by a thick succession of often bright red coloured alluvial to fluvial conglomerates, sandstones and mudstones with distinct well developed calcareous soil horizons deposited in a semi-arid desert environment. We will examine these in detail at the Seagreens location. The calcareous soil horizons represent mature impermeable "hard pan" calcretes that take 10's to 100's of thousands of years to develop - thus attesting to the ephemeral nature of fluvial deposition. The calcretes are locally termed "cornstones" or "cementstones", and were historically mined as a local source of lime (there is an old lime Kiln at Cove Hill). Modern and Quaternary calcretes are well known and described from the Mediterranean.

We will examine 2 main locations. Seagreens and Cove Hill. Seagreens affords an easy accessible set of cliff and foreshore sections through the UORS that allow assessment of depositional facies, reservoir potential, and drilling hazards, whilst Cove Hill exposes some nice foreshore sections through a significant fault zone affecting the UORS and the main faulted contact to lavas and conglomerates of the LORS. At Seagreens we can discuss reservoir characterisation, N/G, baffles and barriers, reservoir quality, strike variability and drilling/operational hazards. At Cove Hill we can discuss the impact of deformation bands on reservoir segmentation, fault juxtaposition and a good Rosebank type hypothetical drilling situation of a sub-seismic scale fault juxtaposing reservoir sands against a succession of interbedded lavas and sediments.

In terms of analogues and links to the offshore UKCS and NCS, the Seagreens UORS sections represents a very good facies analogue for Upper Devonian reservoirs as encountered in eg the Buchan and Claire fields, whilst the LORS is a direct analogue for the Embla field. The UORS interval is also being considered as a CCUS target on the UKCS. The Seagreens sections represent very similar facies and reservoir sections to some of the main producing Triassic reservoirs offshore, such as those encountered at the Snorre and Statfjord field on the NCS and numerous fields in the UK sector. These facies are also the main CCUS reservoir targets in the Northern Endurance project offshore NE England (albeit with a typically high reservoir N/G than we see here at Seagreens). The well-developed calcretes represent permeability baffles and challenging drilling horizons, particularly where silicified, in many Triassic fields (eg Cormorant and Penguins fields clusters).

The faulted section, damage zones deformation bands and associated fault related diagenesis we will examine at Cove Hill are directly comparable to that developed in many NCS and UKCS fields, including producing Triassic and Jurassic reservoirs, as well as being a good "generic" field scale fault zone analogue. Fault controlled secondary barite and permeability reducing deformation bands are a significant factor to predict and understand, both for conventional and CCUS reservoir systems. Recent work on the cross border Peik and Burdock fields cores has highlighted directly comparable fault controlled secondary barite intervals developed beneath intra-reservoir shale baffles within Mid Jurassic Sleipner-Hugin facies.

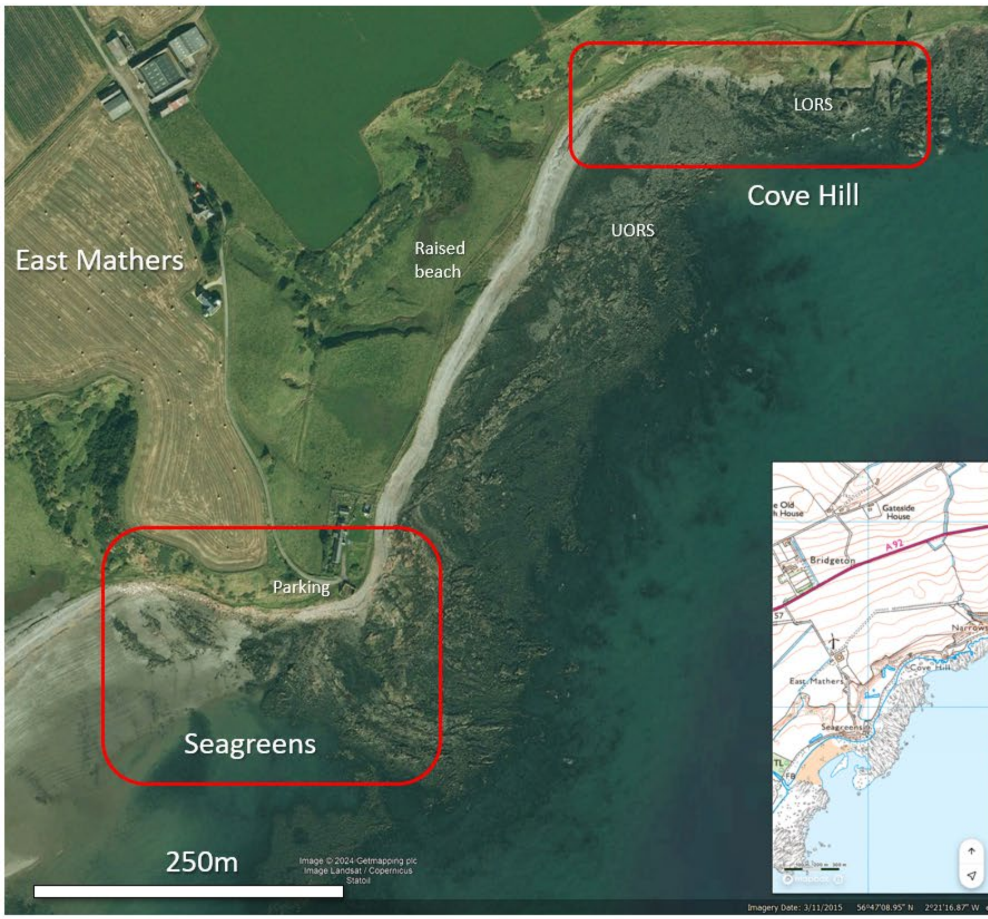
From an age and in part facies perspective, the Scottish Old Red Sandstone has its equivalent in the spectacularly exposed Devonian basins of western Norway such as Hornelen, Kvamshesten and Solund north of the Sognefjord.

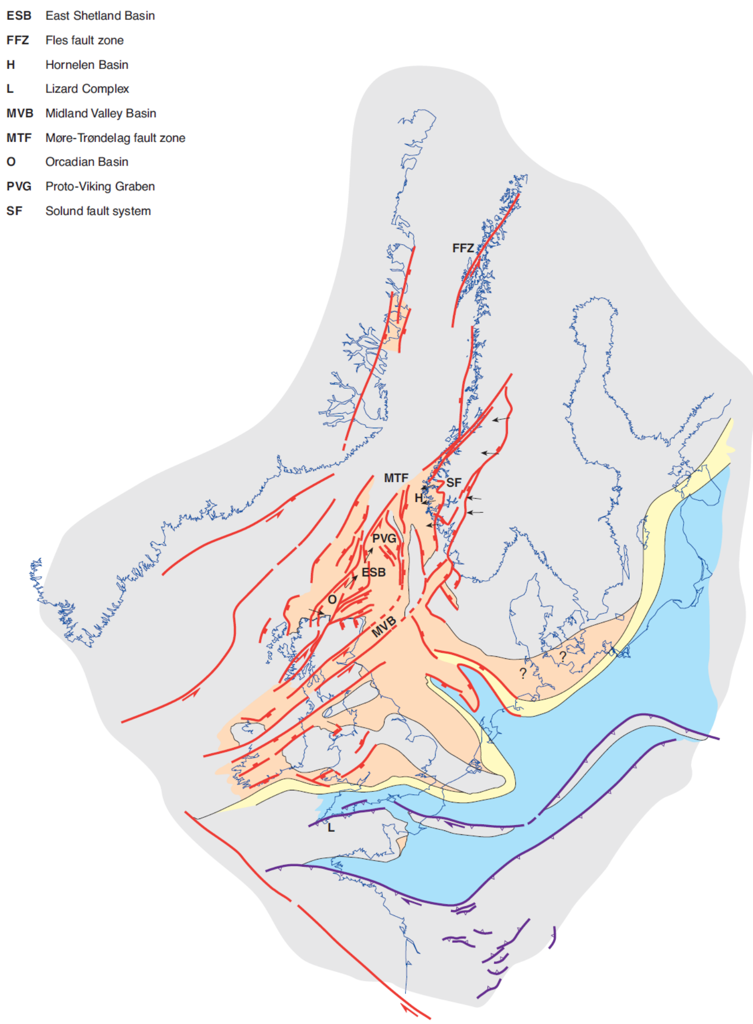



***Location maps***

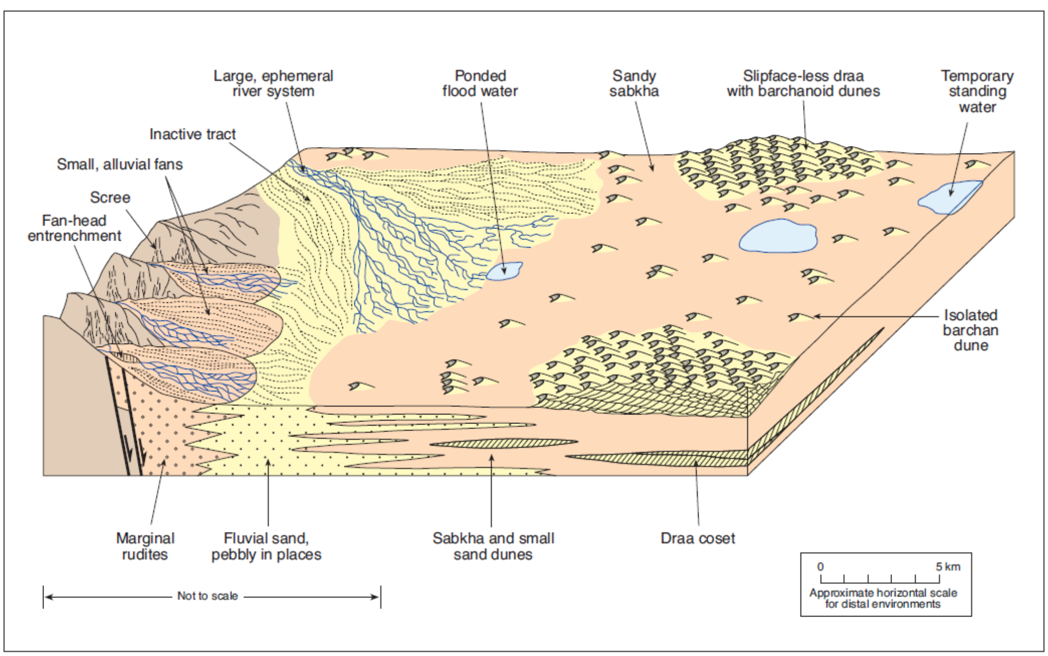
## Seagreens and Cove Hill sections

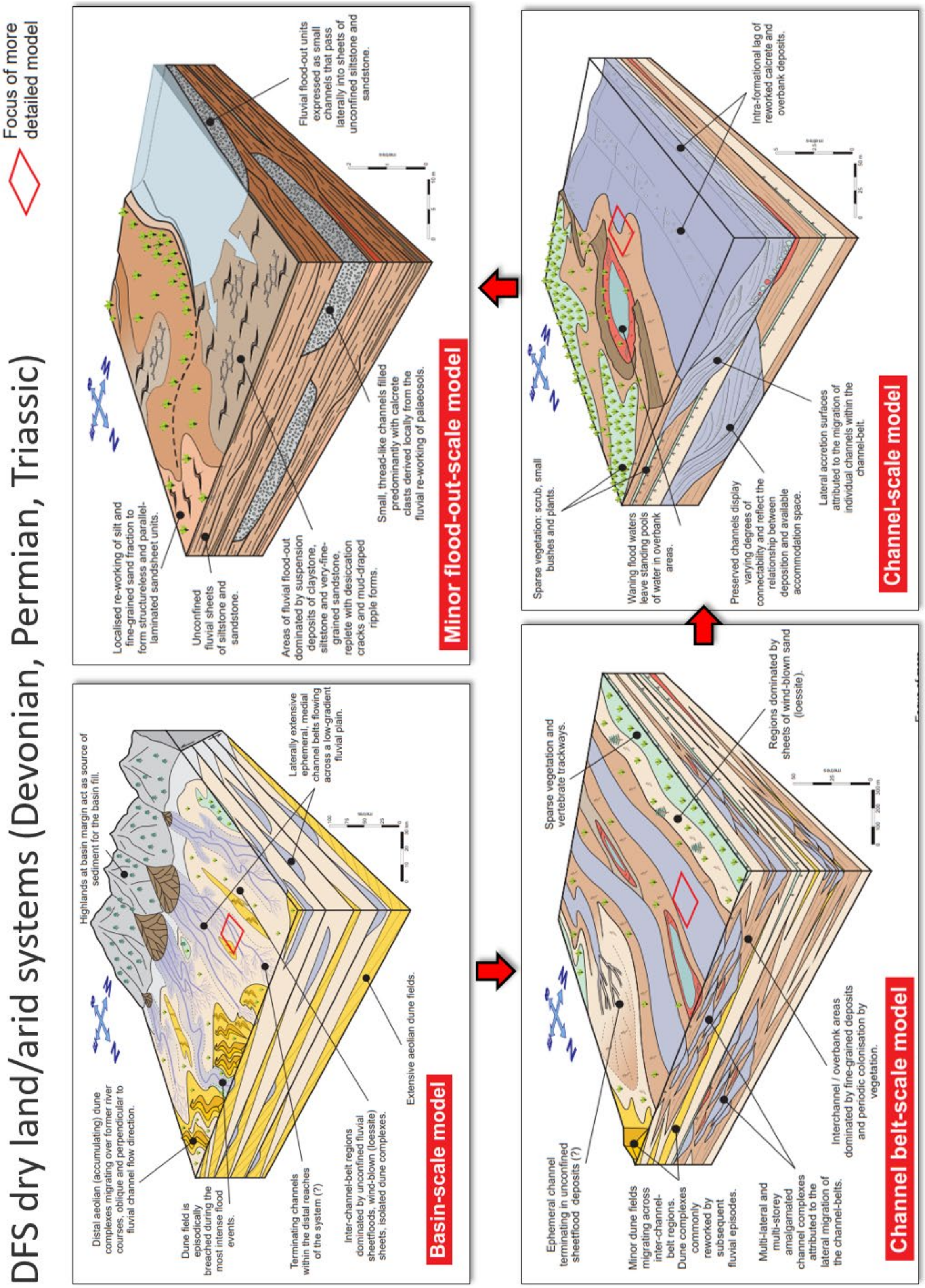
- **Seagreens** – Fluvial cliff and foreshore exposure Up Dev-Carb (UORS)
- **Cove Hill** – Faulted contact Up Dev-Carb fluvial facies (UORS) against Lr Devonian volcanics and interbedded conglomerates (LORS)




Mid to Late Devonian palaeogeography and facies scheme (Millenium Atlas)






Reproduced with permission Nigel Mountney, Leeds University

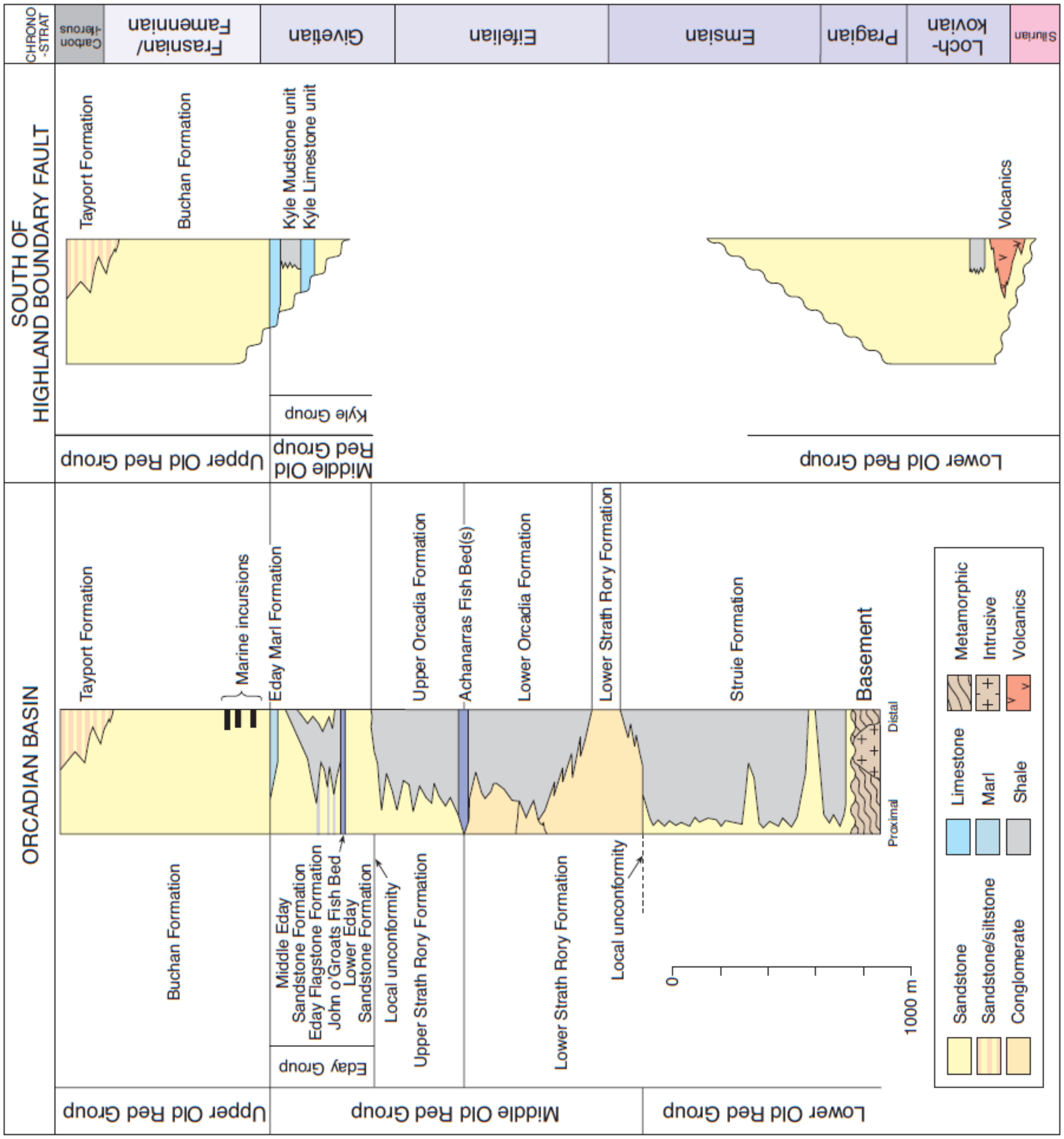
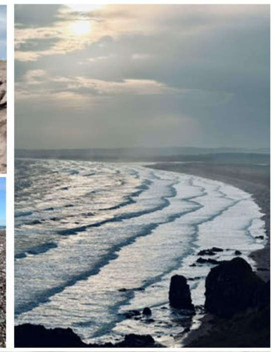


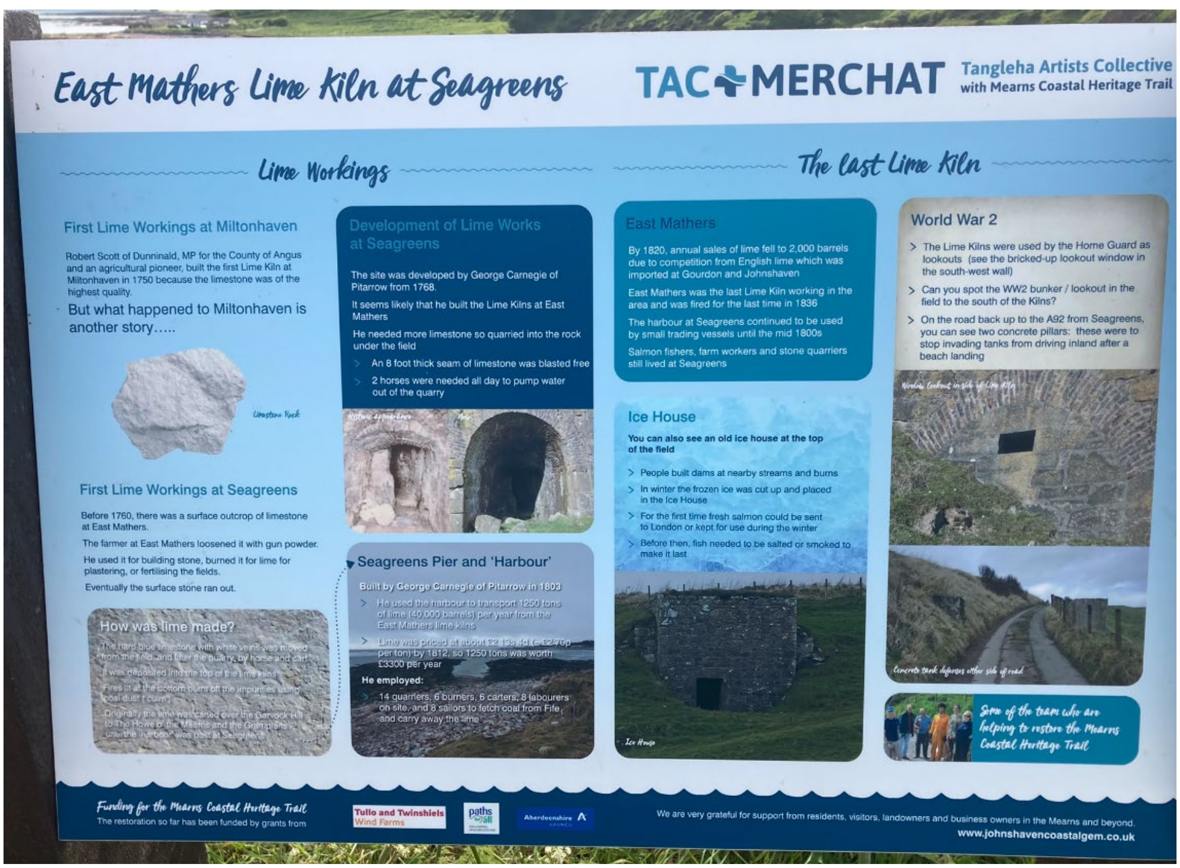

Figure 6.7 *right*
**A stratigraphy for the offshore Devonian in the UK sector.**
This stratigraphy presents modifications to the existing scheme (Cameron et al, 1993a; 1993b); see further discussion in text. Note the conformable nature of the Lower, Middle and Upper Old Red groups in the Orcadian Basin, and compare with the significant gap between the Lower and Upper Old Red groups south of the Highland Boundary Fault.


Aberdeen
Grampian Highlands
HBF
Stonehaven
Dunnoter
HBF
River North Esk
Seagreens
Milton Ness
St Cyrus
River South Esk
Montrose
Lunan Bay




Dynamic and eroding coastline


Side bar
River North Esk
Mid channel bar
St Cyrus
Nature reserve
parking
Salt marsh
Dunes
Shoreface
Shoreface
Mouth Bar
Along shore bars and troughs
Google Earth

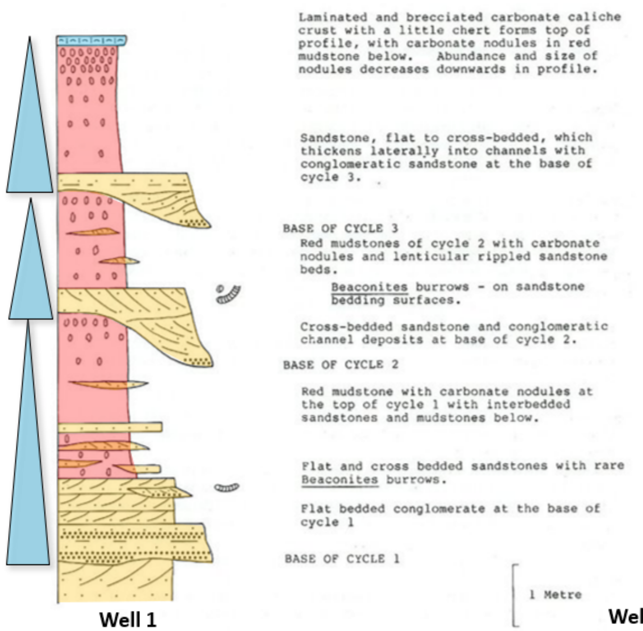

East Mathers Lime Kiln at Seagreens
TAC MERCHAT
Tangleha Artists Collective
with Mearns Coastal Heritage Trail
Lime Workings
First Lime Workings at Miltonhaven
Robert Scott of Dunninald, MP for the County of Angus and an agricultural pioneer, built the first Lime Kiln at Miltonhaven in 1750 because the limestone was of the highest quality.
But what happened to Miltonhaven is another story…..
Limestone Rock
First Lime Workings at Seagreens
Before 1760, there was a surface outcrop of limestone at East Mathers.
The farmer at East Mathers loosened it with gun powder.
He used it for building stone, burned it for lime for plastering, or fertilising the fields.
Eventually the surface stone ran out.
How was lime made?
Development of Lime Works at Seagreens
The site was developed by George Carnegie of Pitarrow from 1768.
It seems likely that he built the Lime Kilns at East Mathers
He needed more limestone so quarried into the rock under the field
An 8 foot thick seam of limestone was blasted free
2 horses were needed all day to pump water out of the quarry
Seagreens Pier and 'Harbour'
Built by George Carnegie of Pitarrow in 1803
He used the harbour to transport 1250 tons of lime (40,000 barrels) per year from the East Mathers lime kilns
per ton) by 1812, so 1250 tons was worth £3300 per year
He employed:
14 quarriers, 6 burners, 6 carters, 8 labourers on site, and 8 sailors to fetch coal from Fife and carry away the lime
The last Lime Kiln
East Mathers
By 1820, annual sales of lime fell to 2,000 barrels due to competition from English lime which was imported at Gourdon and Johnshaven
East Mathers was the last Lime Kiln working in the area and was fired for the last time in 1836
The harbour at Seagreens continued to be used by small trading vessels until the mid 1800s
Salmon fishers, farm workers and stone quarriers still lived at Seagreens
Ice House
You can also see an old ice house at the top of the field
People built dams at nearby streams and burns
In winter the frozen ice was cut up and placed in the Ice House
For the first time fresh salmon could be sent to London or kept for use during the winter
Before then, fish needed to be salted or smoked to make it last
Ice House
World War 2
The Lime Kilns were used by the Home Guard as lookouts (see the bricked-up lookout window in the south-west wall)
Can you spot the WW2 bunker / lookout in the field to the south of the Kilns?
On the road back up to the A92 from Seagreens, you can see two concrete pillars: these were to stop invading tanks from driving inland after a beach landing
Concrete tank defenses either side of road
Some of the team who are helping to restore the Mearns Coastal Heritage Trail
Funding for the Mearns Coastal Heritage Trail
The restoration so far has been funded by grants from
Tullo and Twinshiels Wind Farms
paths for all
Aberdeenshire Council
We are very grateful for support from residents, visitors, landowners and business owners in the Mearns and beyond.
www.johnshavencoastalgem.co.uk

# 2 Seagreens Themes and Tasks

Working in teams of 4-5, observe and characterize the reservoir and non-reservoir sections exposed between Areas 1 to 5. Discuss any potential operational drilling related risks and hazards. Key possible themes to address.

1. Reservoir facies, N/G, reservoir quality, continuity and heterogeneity and strike variability (particularly between Seagreens 1 and Seagreens 2 hypothetical well locations).
2. Recognition and characterisation of any potential Intra reservoir baffles and barriers. Thickness, strike extent, facies.
3. Structural heterogeneity - can you observe any structural related factors that will impact reservoir quality and compartmentalisation?
4. Operational challenges. Can you identify any drilling related issues? In a discovery case the partnership wishes to take a core, how representative will tool investigation depths at well location 1 and 2 be for formation evaluation?

**East Mathers – Seagreens.** Late Devonian-Early Carboniferous. Ephemeral stacked alluvial-fluvial channel fill and calcrete soil cycles developed on migrating braid plain under semi-arid conditions. Mature calcretes = long periods non deposition




**Typical fining upwards cycles**

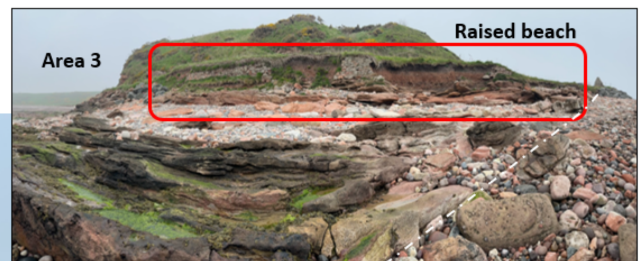
**4** – 1-2m thick laminated to nodular carbonate with local silicified intervals and mudstone patches and root traces. Nodular to brecciated upper surface. Mature silicified calcrete soil profile "hard pan/crust" with evidence of karstic dissolution of upper surface. Based on comparison to present day tropical soil profiles take 10's to 100's thousand years to develop.

**3** – Red siltstones, mudstone and marls with abundant calcareous nodules (caliche), rhizoliths and local reduction spots – wanning fluvial channel fill and overbank facies overprinted by arid soil profile with carbonate nodules precipitating on an alluvial plain under semi-arid climate.

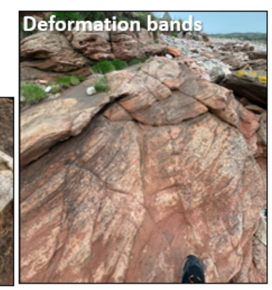
**2** – Cross bedded, current rippled and parallel bedded (PCL) quartzose sandstones. Bedform hierarchy observed indicating wanning flow of individual bedforms. Complex cross cutting erosional contacts. Local growth faults. Local arthropod bioturbation. Rhizolith horizons. Migrating mid channel and braid river bars of alluvial channels. Local cut bank collapse. Arthopod burrows to escape arid surface conditions. Rhizoliths indicate vegetated channel banks.

**1** - Basal conglomerate, erosive base, channelized. Reworked caliche ("cornstone-cementstone") and granite clasts. No LORS volcanics. Considerable reworking of alluvial plain results in high proportion of reworked caliche clasts within channels.


**Areas to examine in detail**







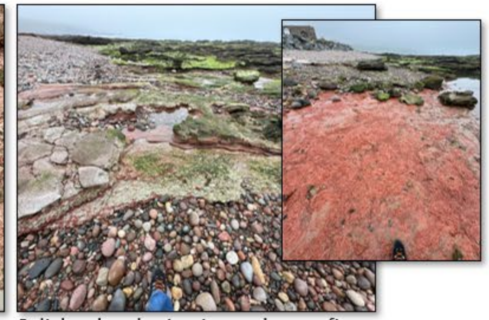

Detail of Area 3 eastern edge

**East Mathers – Seagreens.** Late Devonian-Early Carboniferous depositional cycles. Ephemeral stacked alluvial-fluvial channel fill cycles developed on a laterally migrating braid plain under semi-arid conditions. Representative facies


Reduction spots


Granite wash in channel - immature


Granite + caliche clasts - immature


Caliche developing in mudstone fines


Arthropod burrows or Rhizoliths?


Calcrete with rhizoliths?

Flood plain mudstones cut by shallow channel

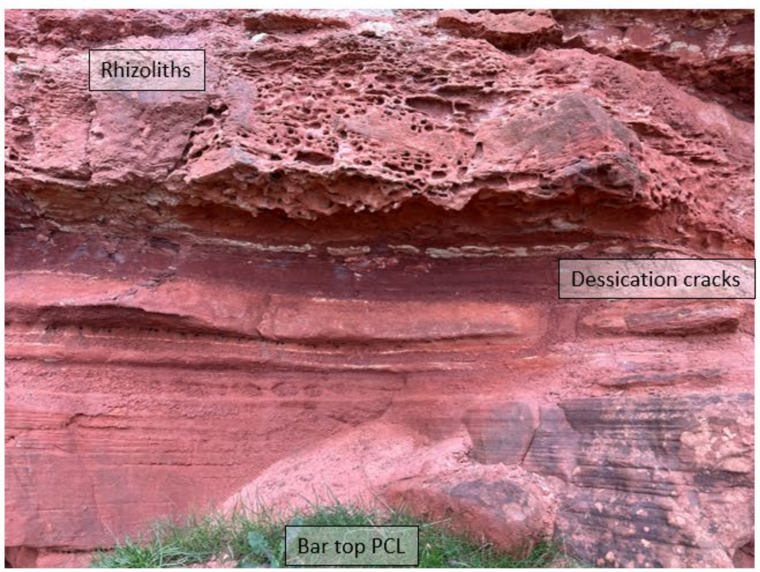
Rhizoliths with root tubules

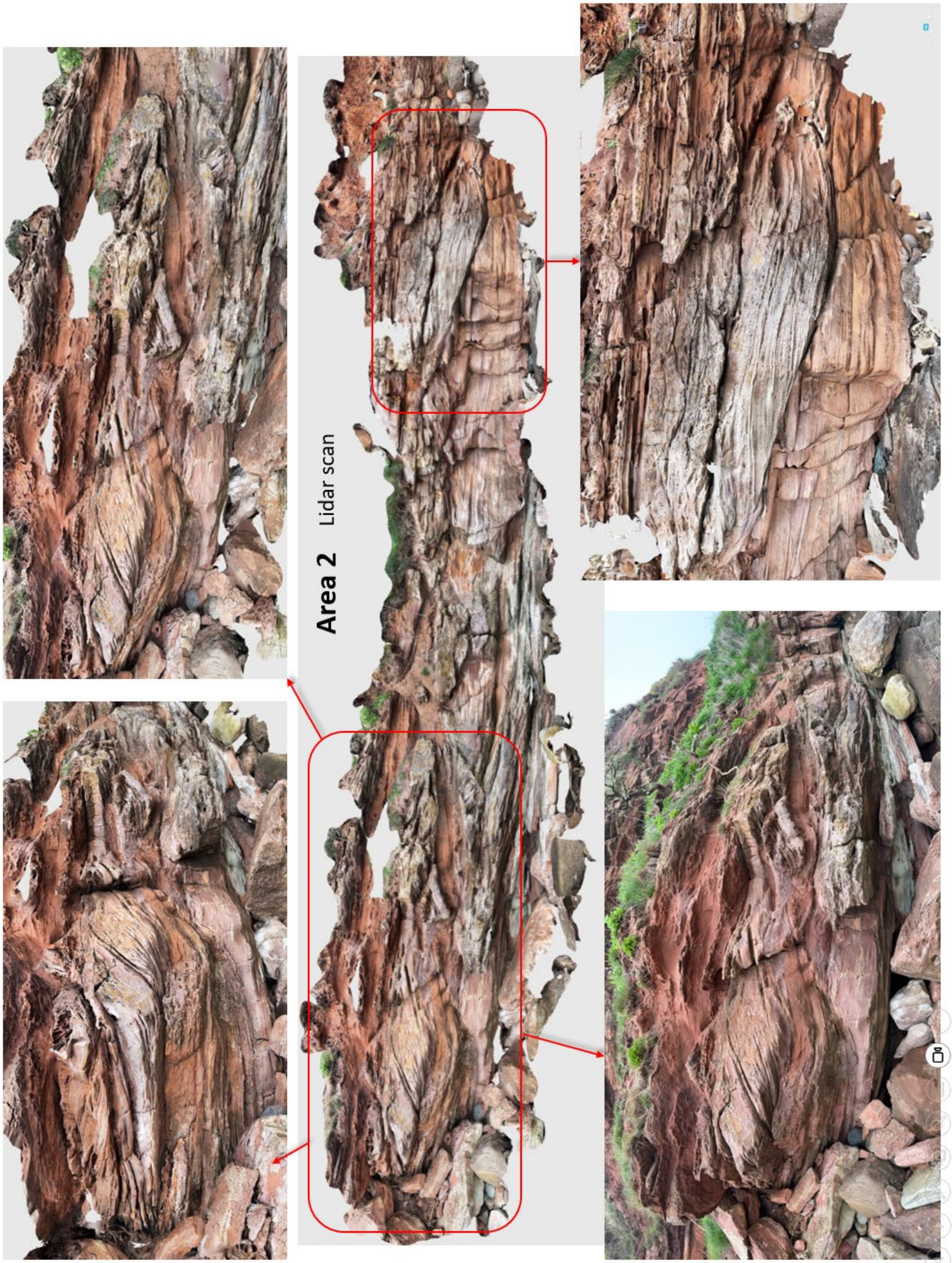

Tabular, tough, planar and current rippled cross bedded sst. Note cycles/bedform hierarchy


Calcite cemented conglomerate

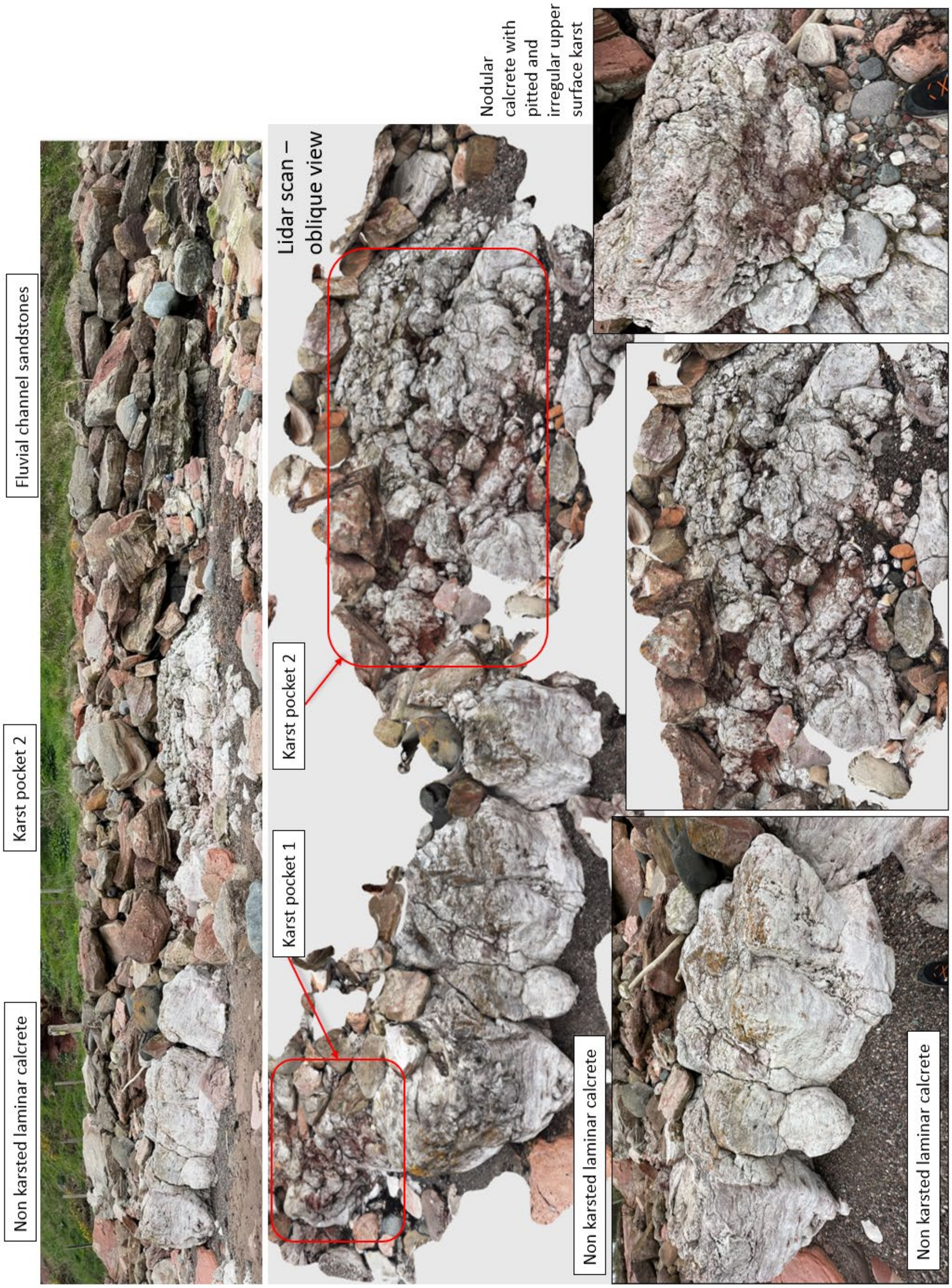

Cong-sst-mudstone + caliche cycles

**East Mathers – Seagreens.** Late Devonian-Early Carboniferous. Ephemeral stacked alluvial-fluvial channel fill and calcrete soil cycles developed on migrating braid plain under semi-arid conditions. Mature calcretes = long periods non deposition



Area 2
Lidar scan

**East Mathers – Seagreens.** Late Devonian-Early Carboniferous mature calcrete with partial karstic dissolution



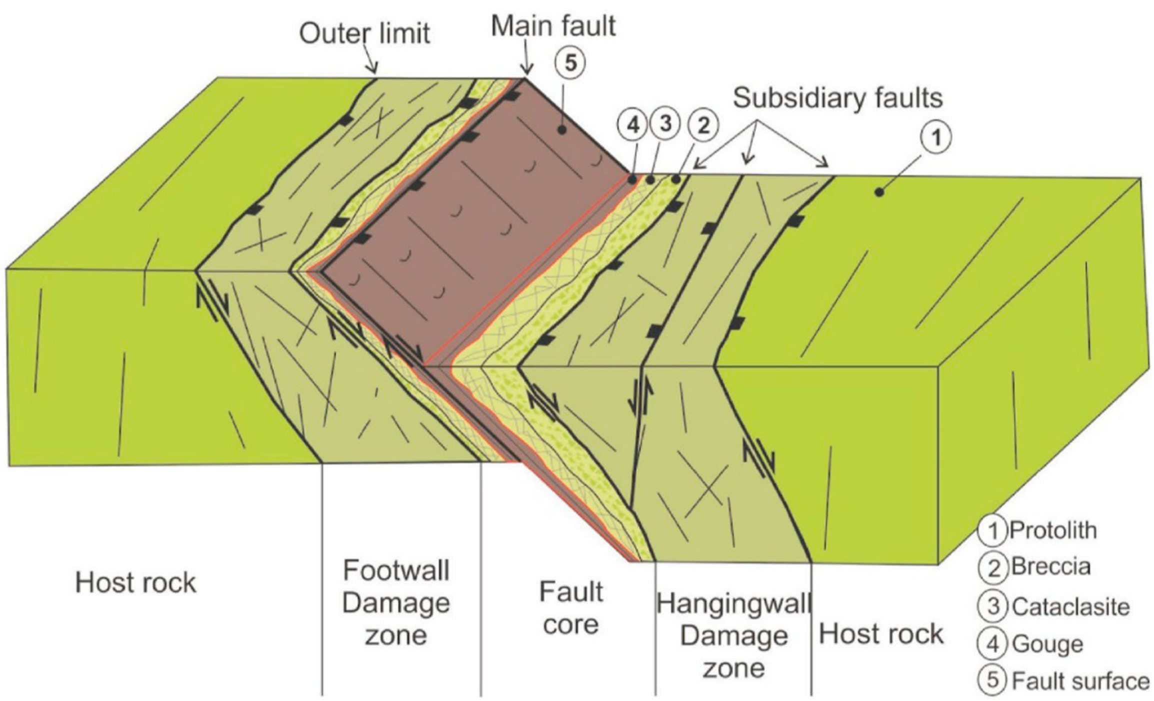
# Notes

# Notes

# 4 Cove Hill Themes and Tasks

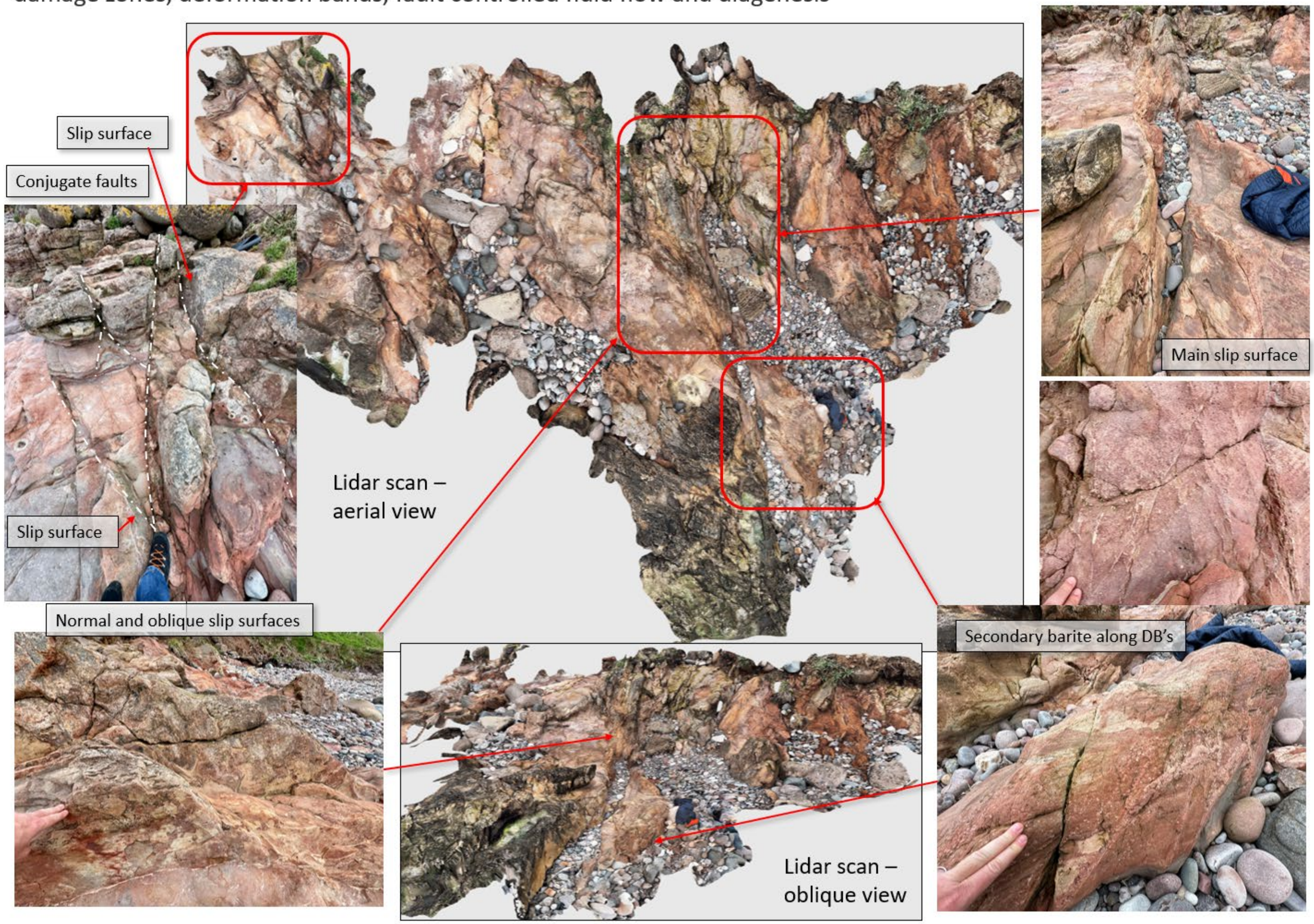
Working in your same groups, observe and characterise the fault(s) and associated damage zones and fault related diagenesis by traversing the outcrop from the UORS reservoir section to the LORS volcanic section walking from south to north (or vice versa if you wish, as the structures are easier to see walking this way).

1. Consider the challenges of drilling a horizontal well in this section. How compartmentalized is the UORS reservoir section likely to be? Utilize the uninterpreted and interpreted Google Earth image to identify and examine potential slip-surfaces and faults – consider this as an horizon seismic slice at reservoir level.
2. Can you constrain the sense of offset and displacement amount in the fault zone (s) - normal or oblique slip faults? - and implications of either?
3. Can you identify fault "cores" and associated damage zones. How wide are the damage zones?
4. What do you think of the density/spacing and impact of the Deformation Bands (DBs) and granulation seams - how will these impact reservoir performance?
5. What is the spatial relationship between secondary cements (calcite, quartz, barite) and the fault zone and deformation bands.
6. How many of the features we have examined in outcrop could we expect to see or predict on subsurface datasets? Can we use any fault scale relationships to predict sub-seismic faults?

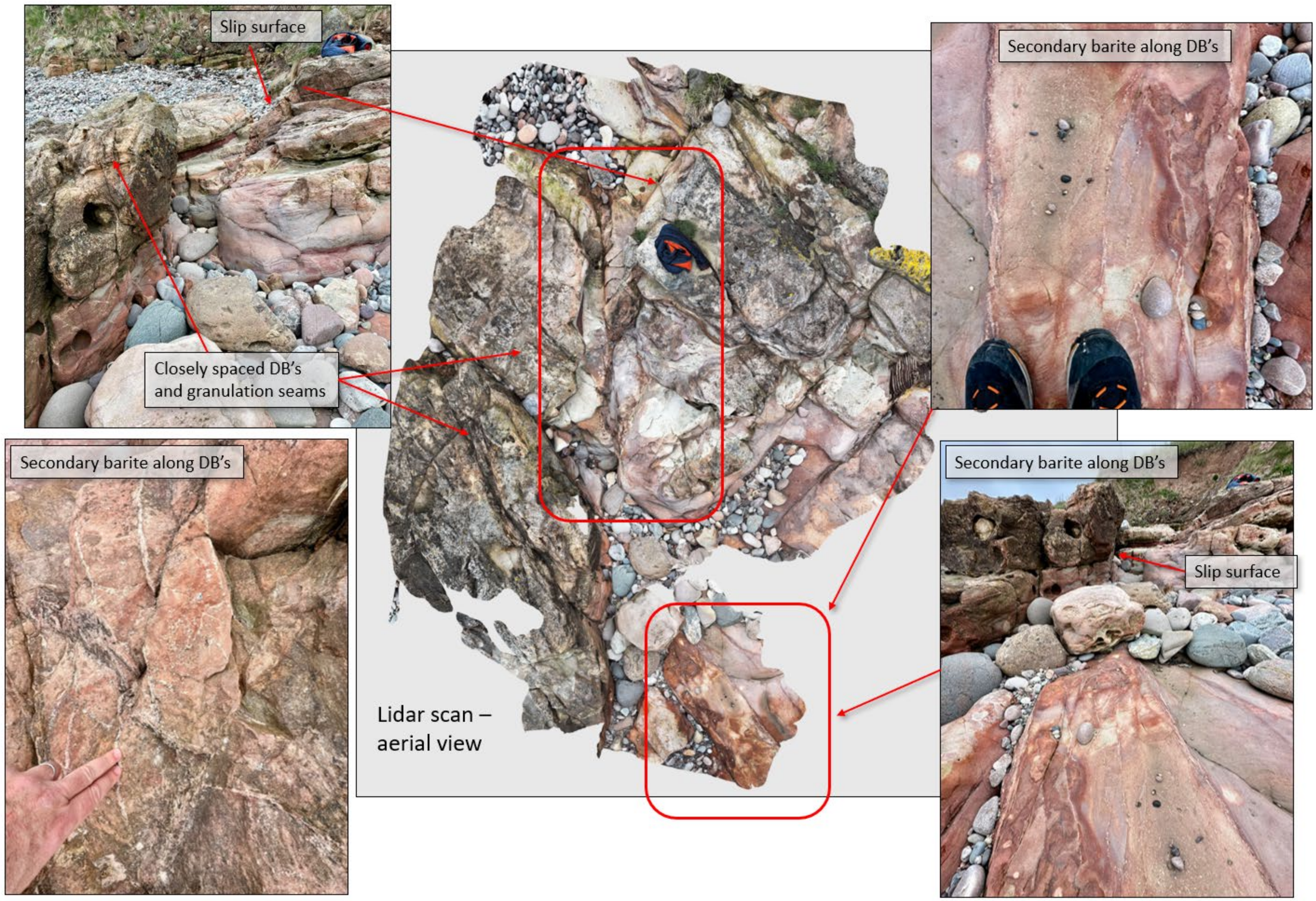



***Typical geometry of a normal fault zone in clastic rocks (Celestino 2020)***

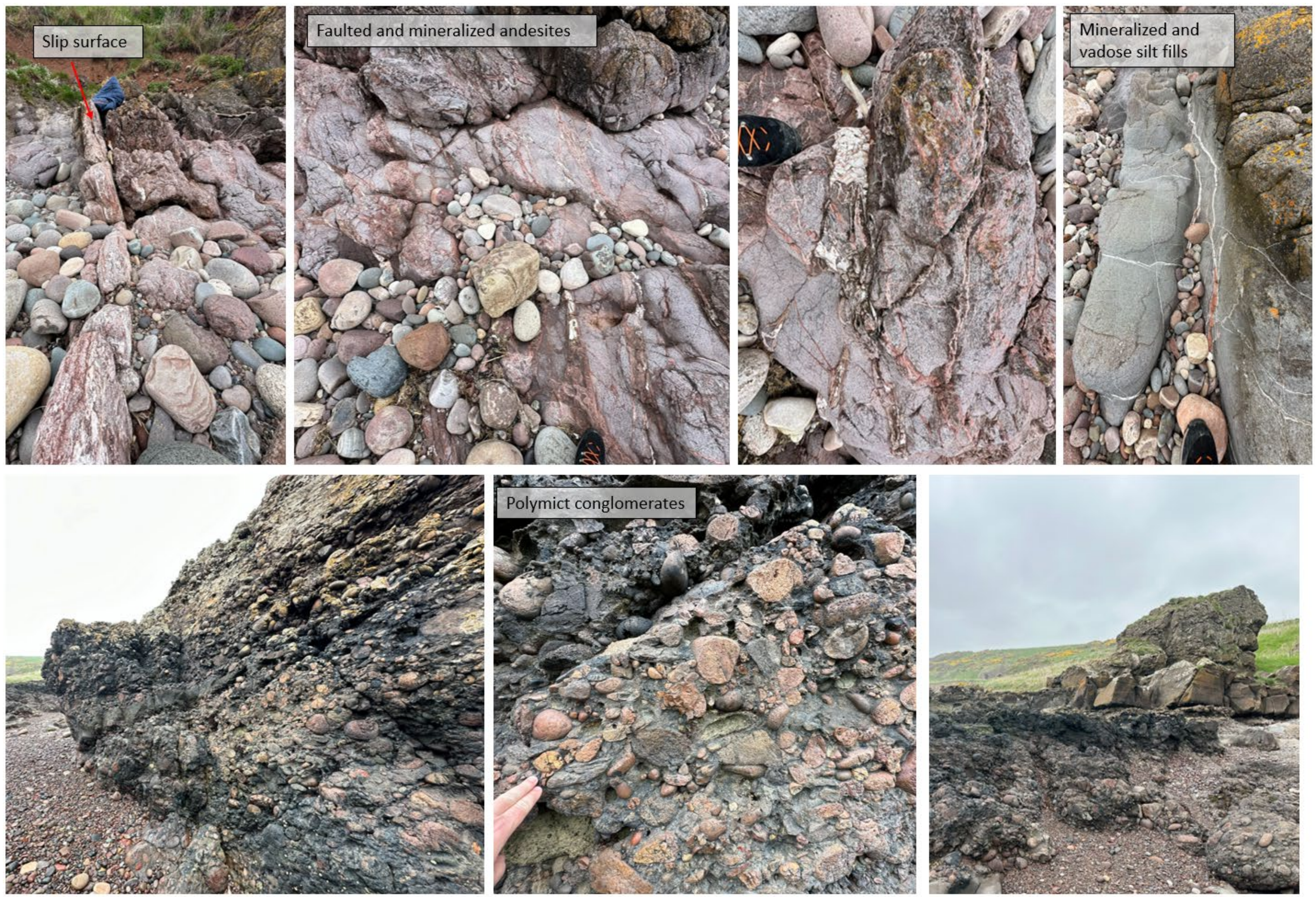
**Cove Hill fault zone** – Lower Devonian volcanics and conglomerates faulted against Upper Devonian fluvial facies. Fault damage zones, deformation bands, fault controlled fluid flow and diagenesis



**Cove Hill fault zone** – Lower Devonian volcanics and conglomerates faulted against Upper Devonian fluvial facies. Fault damage zones, deformation bands, fault controlled fluid flow and diagenesis



**Cove Hill fault zone** – Faulted Lower Devonian volcanics and conglomerates



# NOTES

# NOTES

# 5 Fault seal analysis

## 5.1 Fault seal types

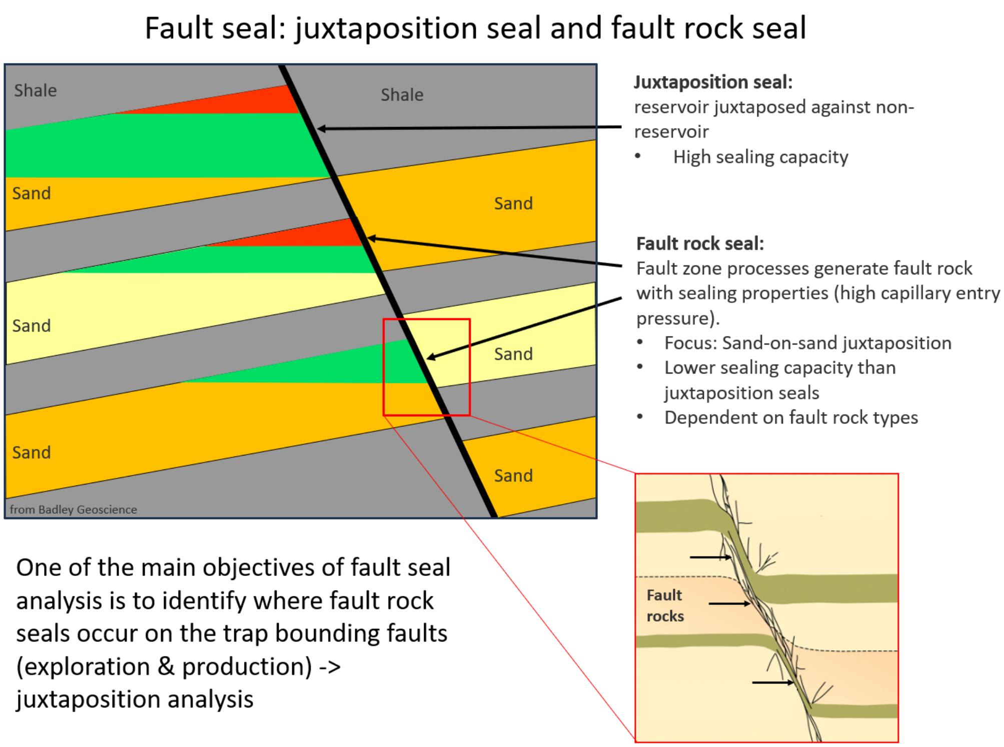
The sealing behaviour of a fault in siliciclastic sediments is controlled either by:

- The juxtaposition of the reservoir against a sealing lithology across the fault
- The fault rock properties created during the fault displacement.

There are two main types of fault seals: Juxtaposition seals and Fault rock seals

**Juxtaposition seals** are created by reservoir rock being juxtaposed with a low permeability rock, either a top seal rock or a tight intra-reservoir stratigraphic unit, which prevents across-fault fluid flow.

**Fault rock seals** are created by a zone of deformed, low permeability rock within the fault core. They will leak when a certain capillary threshold pressure is exceeded, i.e. the minimum pressure required for hydrocarbons to enter the largest interconnected pore throats of a water-wet fault core. Fault rock seals maintain their structural integrity when they fail, because the threshold pressure is not large enough to cause mechanical failure. The maximum hydrocarbon column height a fault rock seal can withstand is controlled by the threshold pressure, while the flow rate across it is controlled by the relative permeability of the seal per Darcy's law.



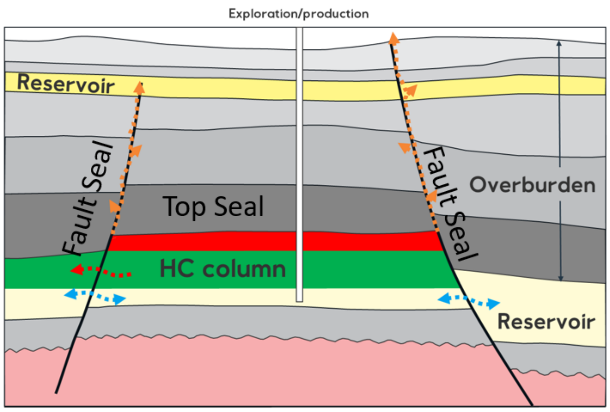
## Seals and Fault seal evaluation

What is a seal?

A substance used to close an opening and prevent air or liquid from flowing through it.

Lithological Seal/Top Seal → Lithology that prevents fluid flow

Fault Seal → A fault that prevents fluid flow across and along




Barriers, Baffles, Conduits

**Barriers**: Top seal or fault seal that holds significant hydrocarbons/$C0_2$ columns over geological timespans.

- Exploration
- CCS
- How much HC/ $C0_2$ can be sealed?

**Baffles**: fault seals may retard flow but hydrocarbons, $C0_2$ or water can migrate (leak) across faults on field-life timescales

- Production
- CCS
- Which fluids will flow, where do they flow through, and at what rate?

**Conduits**: fluids can flow (leak) upwards through connected, permeable pathways

- Exploration, Production, CCS
- Under what conditions, and what are the consequences?

## 5.2 Fault rock types

A range of different deformation mechanisms act upon siliciclastic rocks as faults are created, resulting in an altered rock in the fault core. The deformation mechanism will vary depending mainly on the phyllosilicate content of the rock being deformed (host rock) and the burial depth (mechanical properties, stress magnitudes) at the time of faulting. Usually a combination of shearing, mixing, re-orientation and grain breakage result in macro-porosity being replaced with micro-porosity, causing a corresponding drop in permeability and an increase in capillary threshold pressure to hydrocarbons.

**Disaggregation deformation bands:**

- sandstones < 15 % phyllosilicate content
- shallow burial depths (~500-700m)
- deformation mechanism is inter-granular flow/grain rolling
- sand grains will be rearranged and more densely packed
- porosity and permeability reduction is low, i.e. only 0-1 order of magnitude.

**Cataclastic deformation band:**

- sandstones < 15 % phyllosilicate content

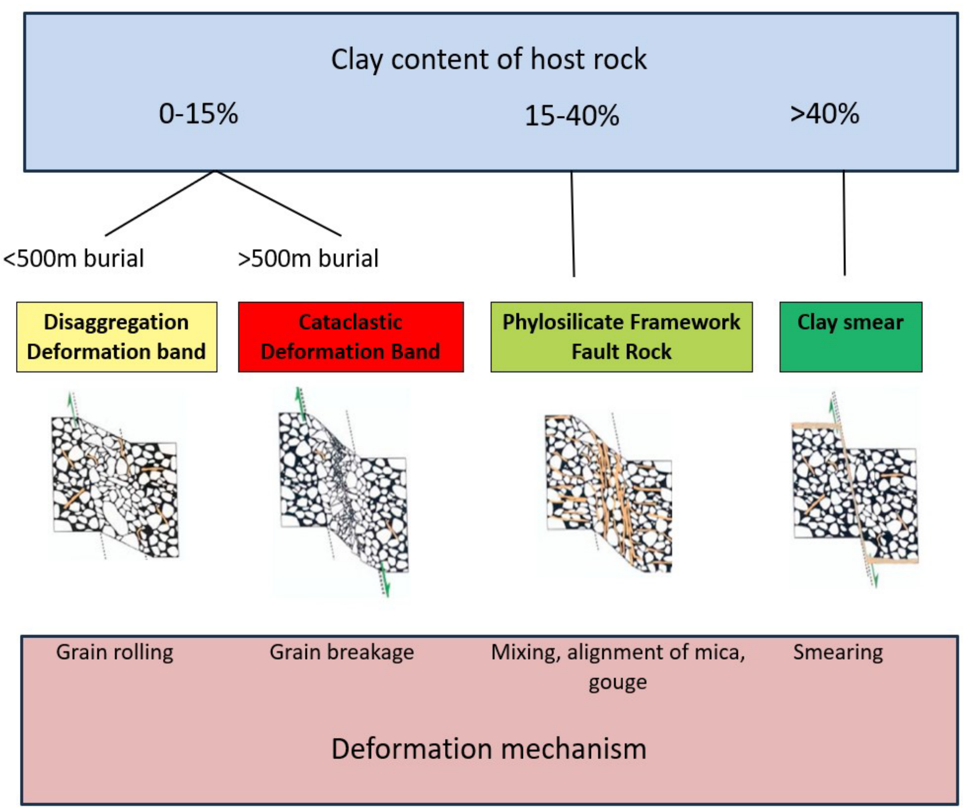
- deeper burial depths (> ~1000m)
- deformation mechanism is grain breakage (cataclasis)
- grain-to grain welding is strong enough to prevent inter-granular flow, but sufficient stress build up causes grain breakage
- grain size is reduced and the macro-porosity is replaced by micro-porosity. Reduction in permeability is significant, typically 2-3 orders of magnitude.

**Phyllosilicate framework fault rocks (PFFR):**

- phyllosilicate content of the host rock between 15 to 40%
- mixing of host rock minerals
- platy clay and mica minerals rearrange and align parallel with the fault plane
- reduction in porosity and permeability is even more severe for PFFR than for cataclasites, i.e. 2-4 orders of magnitude reduction in permeability is quite typical.

**Clay smears:**

- phyllosilicate content of the host rock > 40%
- clay smears may develop given that clays are so enough to deform in a duc le way
- lowest porosity and permeability (typically ~0.0001 mD) of all fault rock types
- With increasing me and burial depth (> ~1000-2000m) rock proper es are changed due to mechanical and chemical compaction, and transition from ductile to brittle deformation. Ability of clay beds to smear is reduced at large burial dept



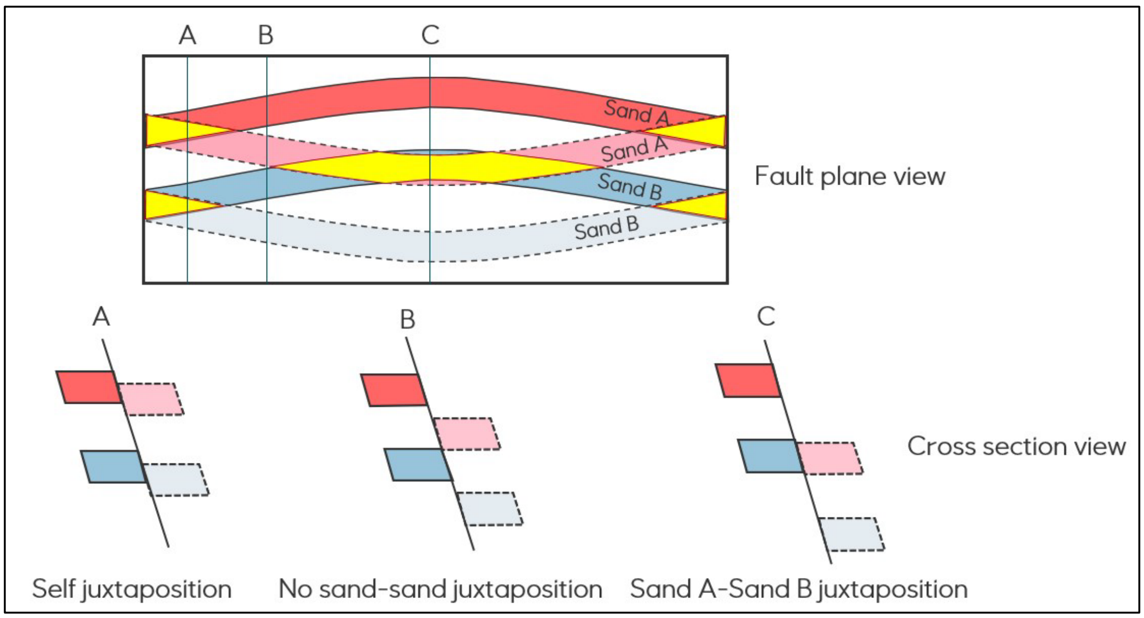
## 5.3 Juxtapositon analysis

Juxtapositon analysis is a key element in fault seal analysis. It is a geometric analysis which aims to define the most permeable flow path through a fault by identifying the location of juxtaposition seals and fault rock seals across a fault.

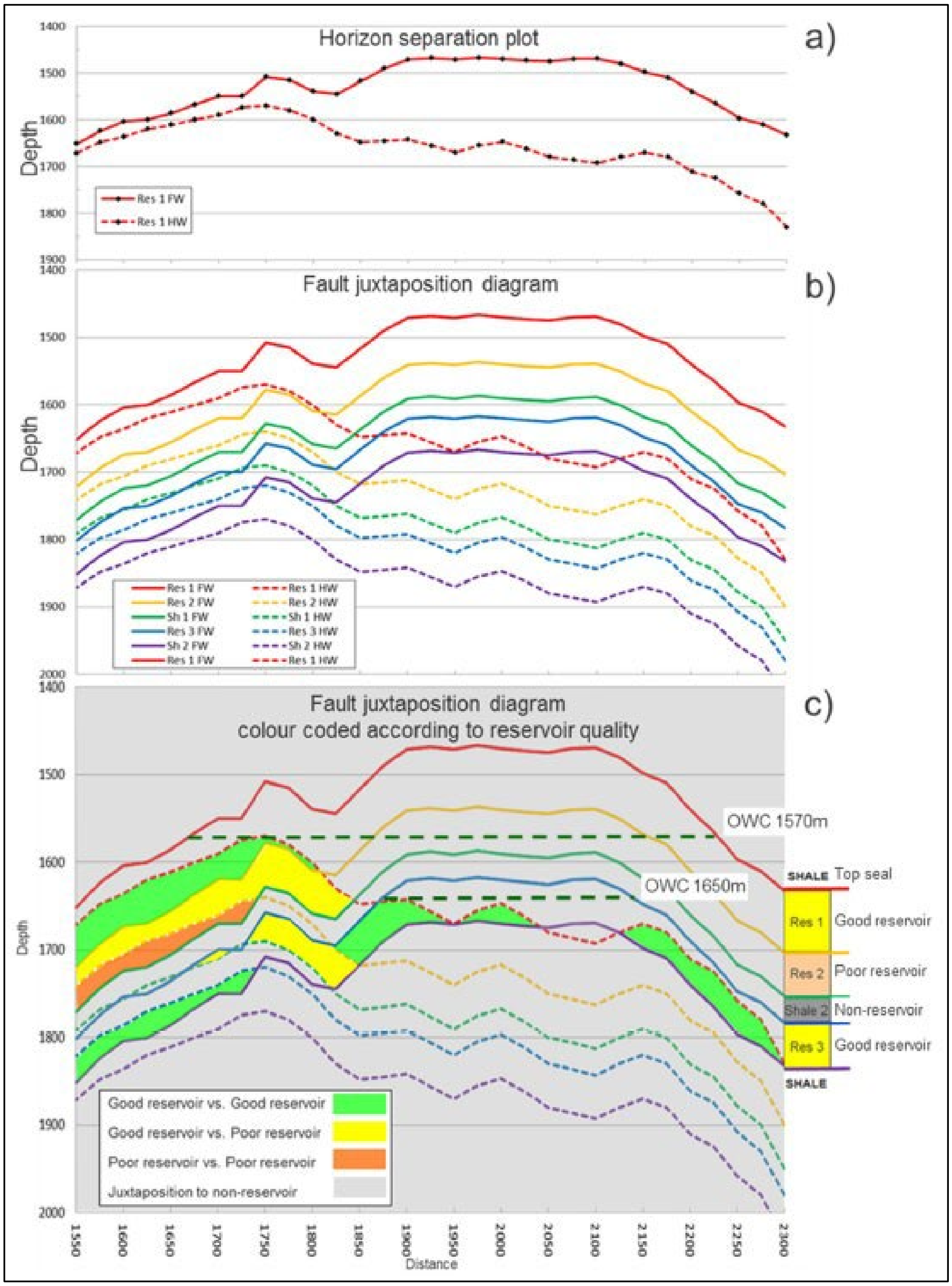
The following methods are used in a juxtaposition analysis:

- Allan diagrams (Fault juxtaposition diagrams)
- 1D Triangle diagrams.

**Allan diagrams** illustrate juxtaposition patterns of reservoir and sealing lithologies across faults. They are used to investigate which parts of a fault rely on either juxtaposition seals or fault rock seals to hold a hydrocarbon column. The technique is needed for all fault bounded traps or compartments with a hydrocarbon column that relies on lateral fault seal, and it is therefore used in exploration and production.




***Concept of an Allan diagram showing juxtaposition of sands and non-reservoirs (shales, in white) across a fault.***



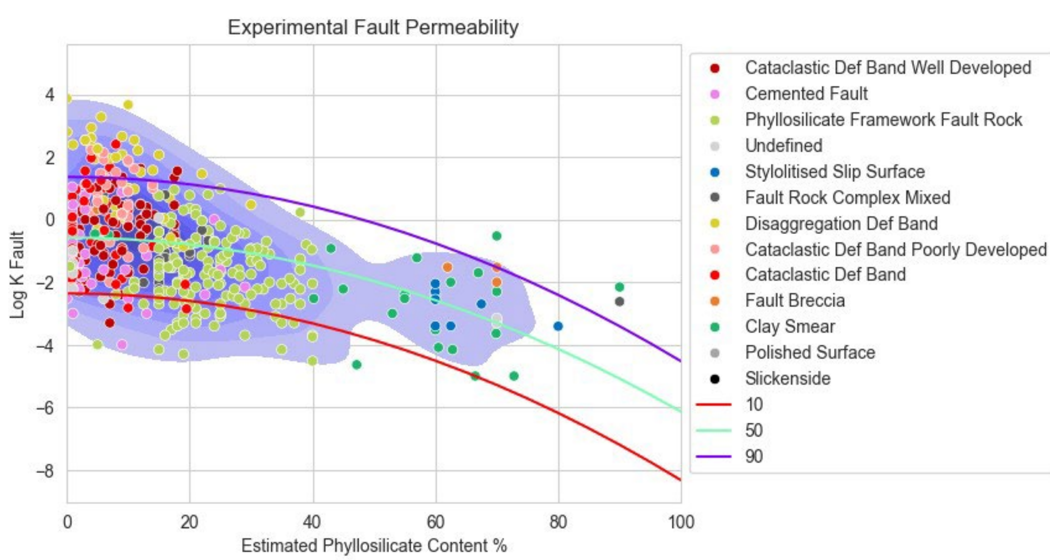

***Steps of Fault juxtaposition analysis. a) Create Horizon separation plot; the footwall and hanging wall cut-off lines of the top reservoir surface plotted along the fault. b) Fault juxtaposition diagram; footwall (solid lines) and hanging wall (dashed lines) stratigraphic intersections with the fault plane. c) Fault juxtaposition diagram colour coded according to reservoir quality. Res1 in the FW is leaking at OWC 1570m due to good vs good reservoir (sand-on-sand) juxtaposition. Res3 is leaking at OWC 1650m.***

## 5.5 Modelling of fault rock properties

In order to model fault rock properties, we use measurements from core samples of fault rocks. Equinor has a large database of these measurements which include fault rock permeability and fault rock capillary threshold pressure.

Faut rock permeability depends on a number of factors, including the fault rock type, the phyllosilicate content of the fault rock and the depth of the fault rock. Both the depth of deformation and the maximum burial depth are significant. In addition, the host rock properties such as permeability and grain size have an influence on permeability. The fault permeability estimated from analysis of these data is used in the calculation of transmissibility multipliers that are used for reservoir simulation. The transmissibility multiplier also requires an estimate of fault rock thickness, which is estimated from an empirical relationship between fault throw and fault rock thickness, measured in outcrop.

Similarly, measurements of mercury injection capillary threshold pressure from fault rocks can be used to constrain maximum column heights across faults. Capillary threshold pressure is a function of fault rock type and fault rock phyllosilicate content, in a similar manner to permeability, although capillary entry pressure increases with increasing phyllosilicate content. Once the mercury injection threshold pressure is estimated, some simple equations allow estimation of column height given different assumptions about the fluids either side of the fault. However, in practice we also use direct measurements of column heights from hydrocarbon fields to constrain column heights in a prospect.

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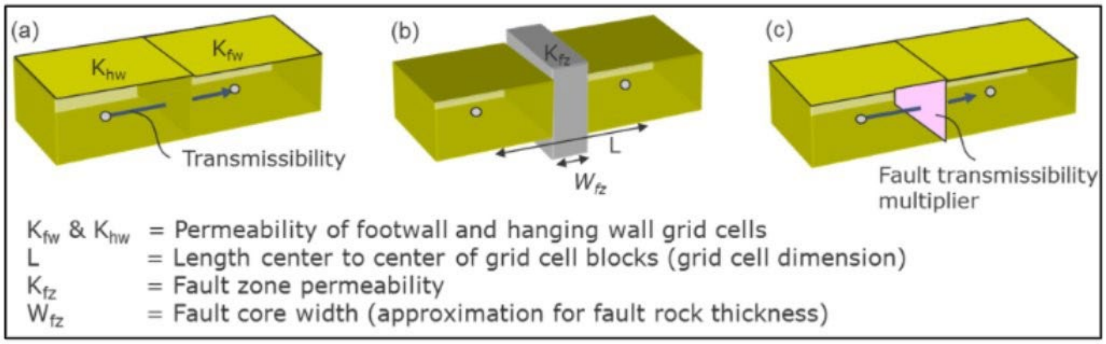
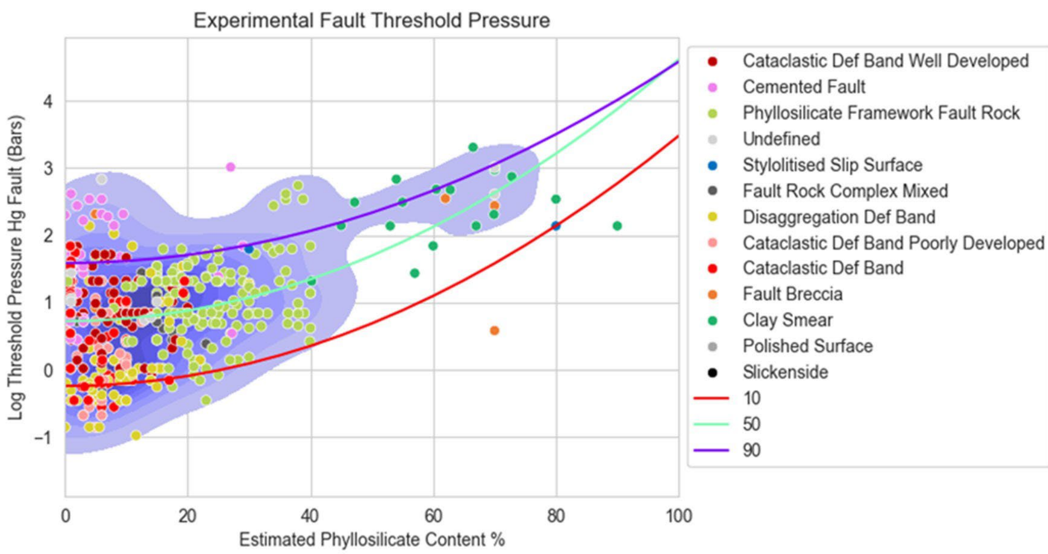
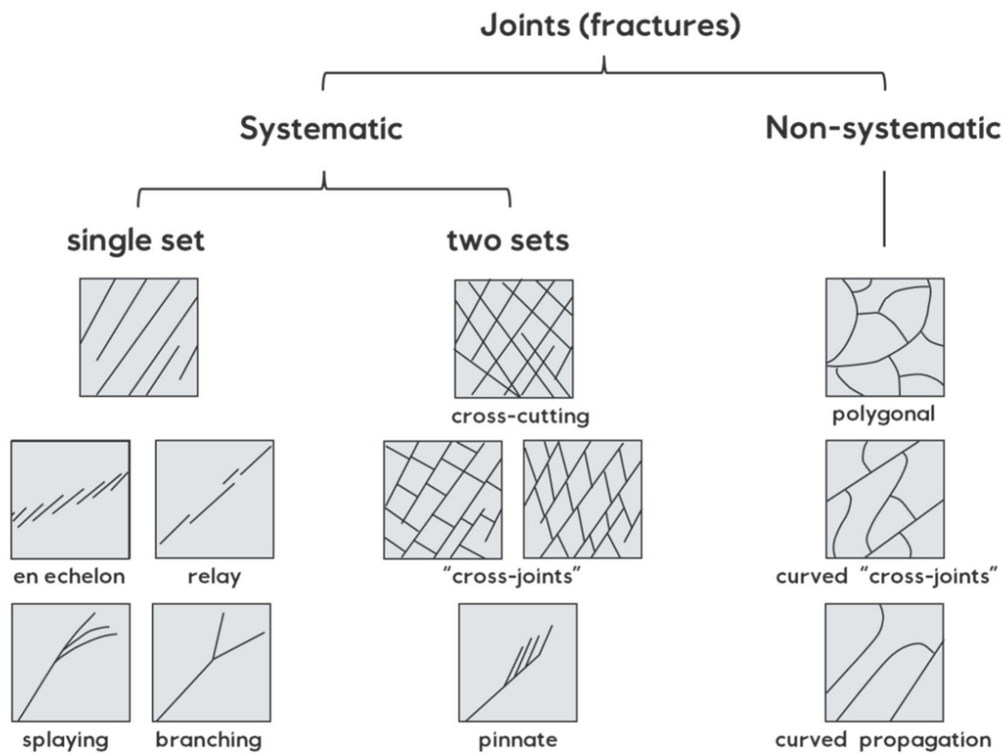
***Core measurements of Log permeability (mD) versus estimated fault rock phyllosilicate content from Fault Rock Properties Database. Best fit regression lines included at $P_{10}$, $P_{50}$ and $P_{90}$.***

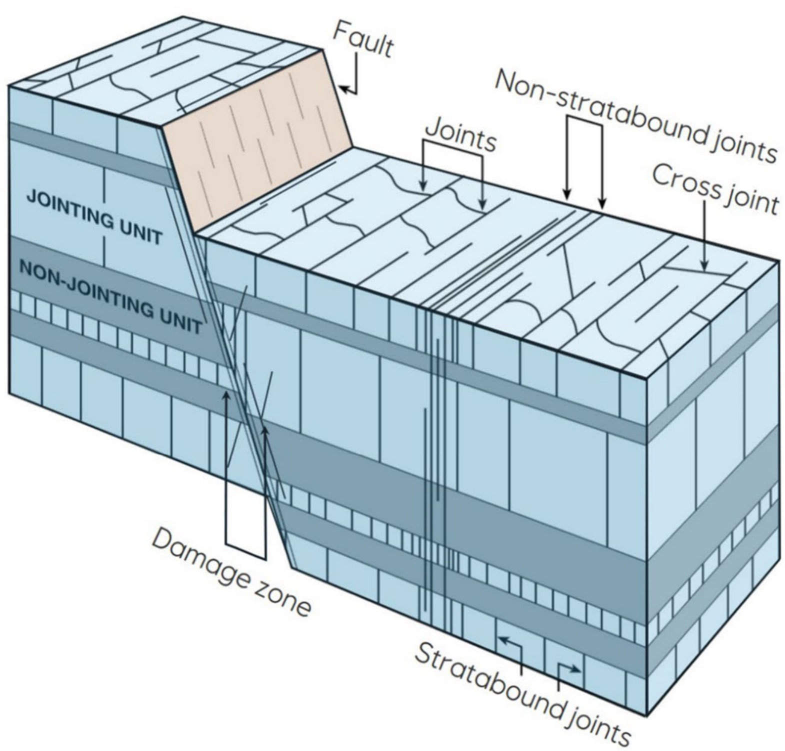



***Derivation of the fault Transmissibility Multiplier. a) The transmissibility is defined to represent the flow between adjacent cells, b) the fault rock permeability and fault core width are estimated, c) the fault TM is calculated for an equivalent thin plane.***

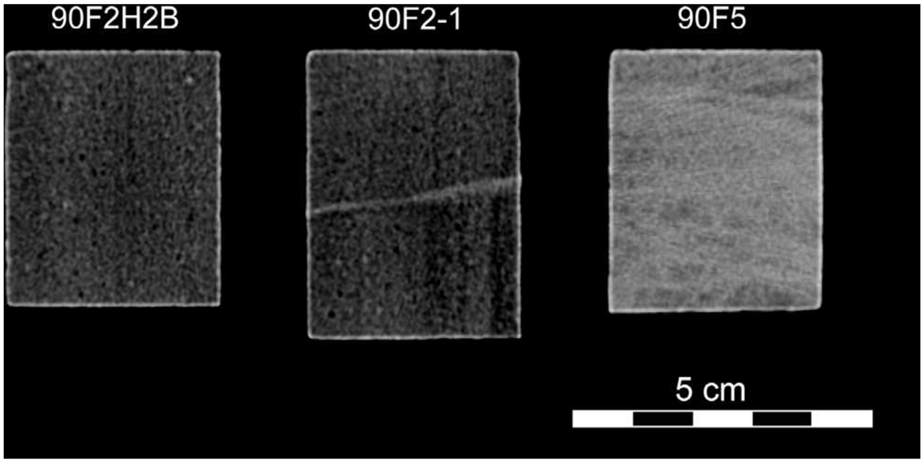



***Core measurements of Log mercury injection threshold pressure versus estimated fault rock phyllosilicate content from Fault Rock Properties Database. Best fit regression lines included at $P_{10}$, $P_{50}$ and $P_{90}$***

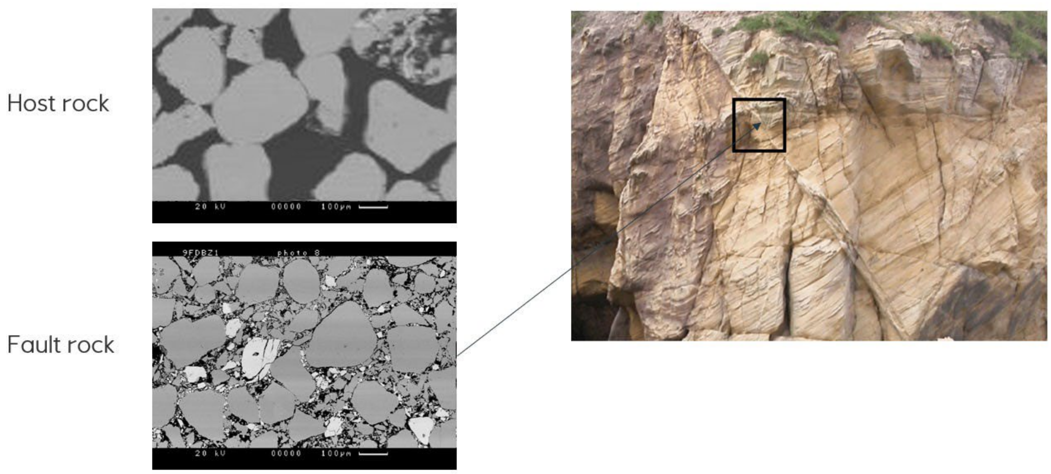


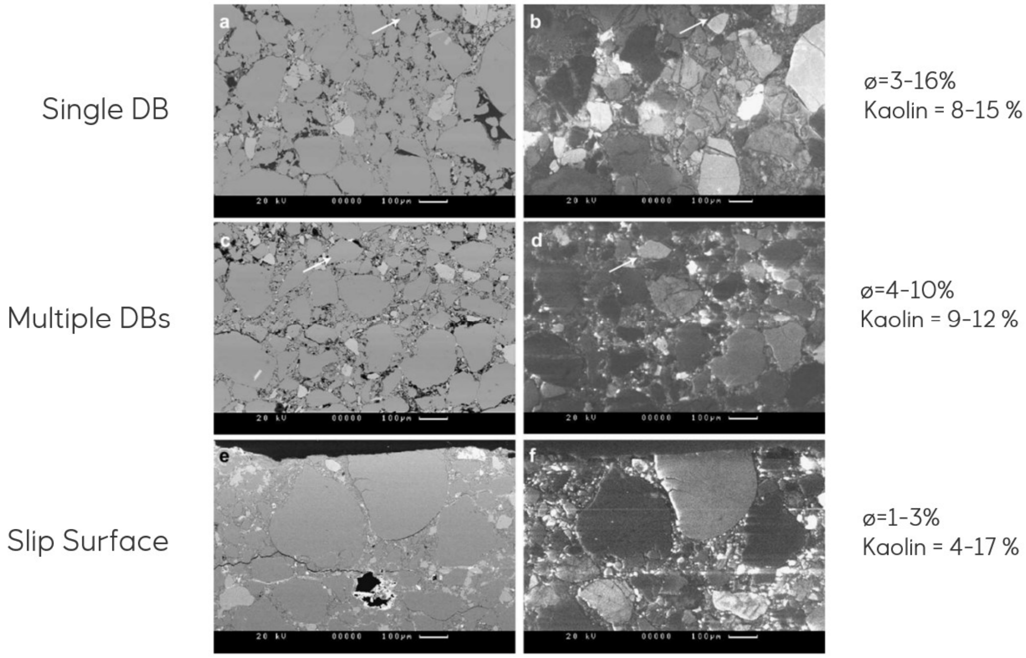

***Terminolgy for describing fracture systems***



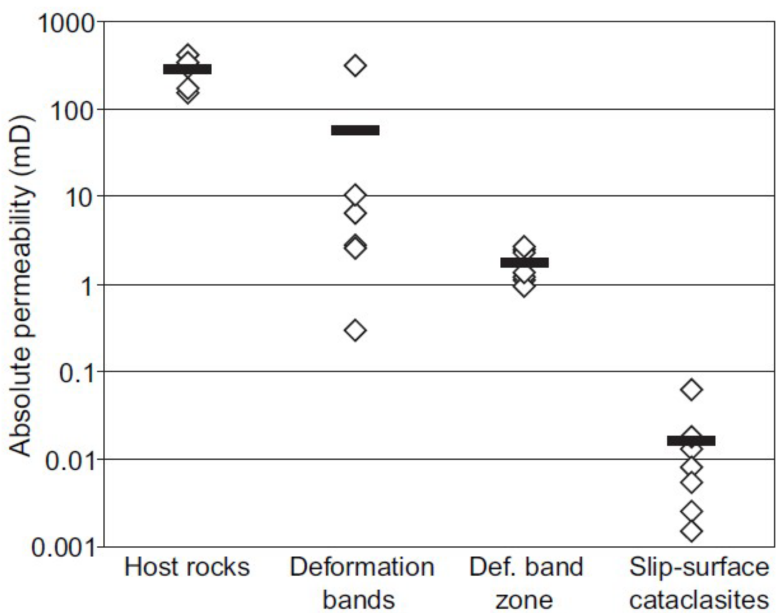

***CT scans through matrix, a single deformation band and a cluster of deformation bands (left to right). The brighter parts of the image are dense, whereas the darker parts are of low density. From Tueckmantel et al. (2012).***



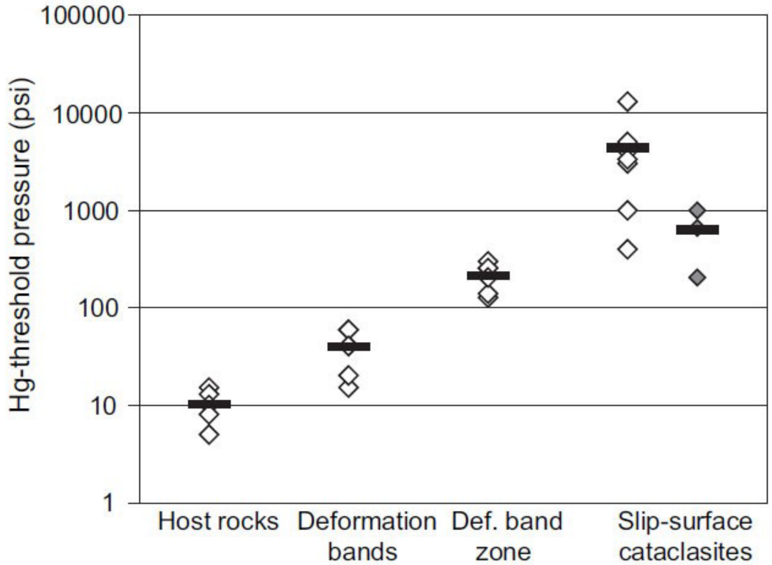

***Scanning electron micrographs from the host rock and from a deformation band cluster. The fault rock shows clean indication of grain breakage and grain size reduction. From Tueckmantel et al. (2012)***




***Electron Micrographs (left) and Cathode Luminesence images (right) of structures in the Permain sands at Cullercoats. In the electron micrographs, the quartz grains are grey, feldspar grains are white and the porosoity is black. Note the lack of intergranular porosity in the sample close to the fault slip surface. From Tueckmantel et al. (2012)***




***Comparison of absolute gas permeability of host rocks, single deformation bands, deformation band zones and slip-surface cataclasites. The black bars give arithmetic means. From Tueckmantel et al. (2012).***




***Comparison of mercury threshold pressure of host rocks, single deformation bands, deformation band zones and slip-surface cataclasites. Filled symbols represent unsealed slipsurface cataclasite samples (see text). The black bars indicate arithmetic means. From Tueckmantel et al. (2012)***

## 9.1 Glossary of Terms

**Barite –** the mineral formed of $BaSO_4$. This is a characteristically dense mineral that can be formed hydrothermally.

**Damage zone** - diffuse zone of fracturing around a fault.

**DST** - drill stem test.

**Effective stress** – the difference between the total stress and the pore pressure. It is the stress that keeps particles together.

**Extended Leak-off test (XLOT) -** a drilling operation for estimating minimum horizontal stress (shmin), involving increasing the mud pressure in an open and isolated section of wellbore, below the casing shoe, in order to create a small tensile fracture. The test consists of two or more cycles, providing a more accurate measure of shmin (fracture closure pressure) than conventional, single cycle leak-off tests.

**Fault** - a shearing mode fracture. Can be of any size.

**Fault core** - the central zone of a fault that usually contains crushed and rotated fragments.

**Fault Transmissibility Multiplier** – a reservoir simulation parameter for capturing the reduction in flow across the fault plane. Calculated from the geometrical parameters of the grid, the host rock permeability, fault rock permeability and fault rock thickness.

**Fracture** - generic term for a structural discontinuity such as a joint, fault or stylolite.

**Joint** - an opening mode fracture with no visible shear.

**Lithostastic stress (Sv) –** one of the three principal compressive stresses; assumed to be vertical. The pressure exerted by the weight of the overburden, (both the overlying rock and pore fluids), on a formation. In extensional basins at depths of interest for hydrocarbon exploration, the lithostatic stress magnitude is generally the greatest of the principal stresses.

**Maximum horizontal stress (Shmax)** - one of the three principal compressive stresses, horizontal, greater than Minimum horizontal stress and perpendicular to it. In extensional basins, shmax magnitude is intermediate between Sv and shmin. The orientation of Shmax can be determined from borehole breakouts observed in image or caliper logs.

**Mercury injec on Capillary Pressure (MICP)** - a method for measuring capillary seal capacity directly from small core plugs or cuttings. Mercury Is injected into dried samples at incrementally increasing pressures. As the pore spaces are invaded by the mercury, capillary entry and threshold pressures can be inferred by inflections in the pressure profile.

**Minimum horizontal stress (Shmin)** - one of the three principal compressive stresses; horizontal, less than Maximum horizontal stress and perpendicular to it. In extensional basins, shmin is the least principal stress. Tensile hydraulic fractures propagate perpendicular to Shmin. Shmin is obtained using direct methods such as the extended-leak-off and mini-frac tests or modelled using equations like the poroelastic equation.

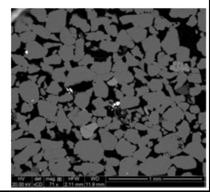
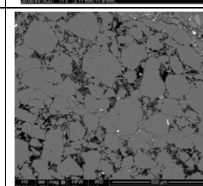
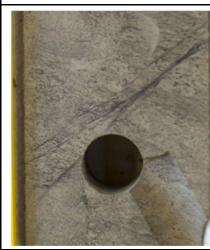
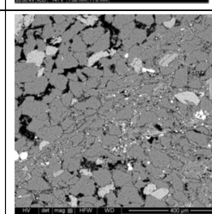
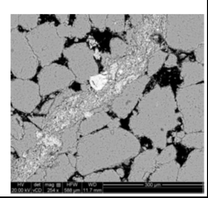
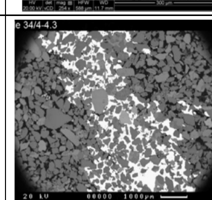
**Phyllosilicate** – sheet silicate minerals, including clay minerals and micas.

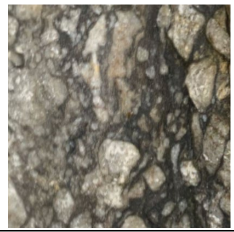
**Shale Gouge Ratio** – and estimate of the shale content of the fault rock, calculated from the proportion of shale that has been displaced past a given point on the fault.

**Vein** - a mineral-filled fracture.

## 9.2 Fault Rock Types

The description of fault rock types has been brought into Equinor's standards. Below is a table that shows a shortened version of the standard description. The terms gouge and fault breccia are more often used of larger faults, especially those described in outcrop, whereas the other terms are used for description of smaller faults in core. The terms slickenside and polished surface are surface features of fault rock slip surfaces.

| Fault Rock Type | Descrip on | Photograph | Electron micrograph | Souce |
|---|---|---|---|---|
| Disaggregation Def Band | Fault rock with < 15% Clay. Deformation band form by disaggregadtion and translation of grains under shear. |  |  | Johan Castberg 7220/7-1 |
| Cataclastic Def Band | Fault rock with < 15% Clay. Deformation band with cataclasis and grain size reduction. |  |  | Johan Castberg 7220/7-1 |
| Phyllosilicate Framework Fault Rock | Fault rock with 15-40% clay. These tend to be thin bands that are darker than the host rock. Characteris cally developed in impure, finely laminated sands. |  |  | Johan Castberg 7220/7-1 |
| Clay Smear | A fault rock of >40% shale or clay, usually deformed by shear, injection or abrasion, containing aligned phyllosilicate minerals and <10% clasts. |  |  | Heidrun; Johan Castberg 7220/7-1 |
| Cemented Fault | Fault that is largely cemented (not a deformation band). |  |  | Snorre 34/4.3 |

| | | | | |
|---|---|---|---|---|---|
| Gouge | Fault rock with very small grain size, with 10 to 30% visible clasts. |  | | Field photo, Hartley Steps Northumberland |
| Fault Breccia | Fault rock with angular clasts in finer matrix. More than 30% visible fragments (cf. gouge) |  | | Field photo, Sugarsands Bay, Northumberland |
| Slickenside | Fault surface with grooves or lineations indica ng the slip direction. |  | | Gulfaks NO /10 C - 38A |
| Polished Surface | Fault slip surface with polished surface, usually associated with organic rich shales |  | | Gulfaks NO /10 C - 38A |

## Accident - calling for assistance

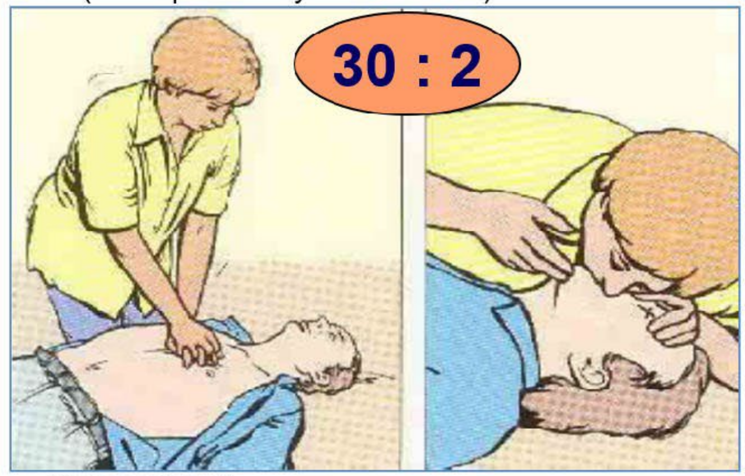
When calling for assistance, the message should include the following points:

- Who is calling
- What has happened and where
- How many are involved
- What assistance do you need
- How to be contacted back

**999**

## First aid

CPR (cardiopulmonary resuscitation)




- Unconscious?
- Does the person breathe normally?
- Call 999 local emergency first
- 30 chest compressions
- 2 rescue breaths

Recovery position