



Endmember lithological variability of the Triassic Mercia Mudstone Group, northwest England: implications for nuclear waste disposal concepts

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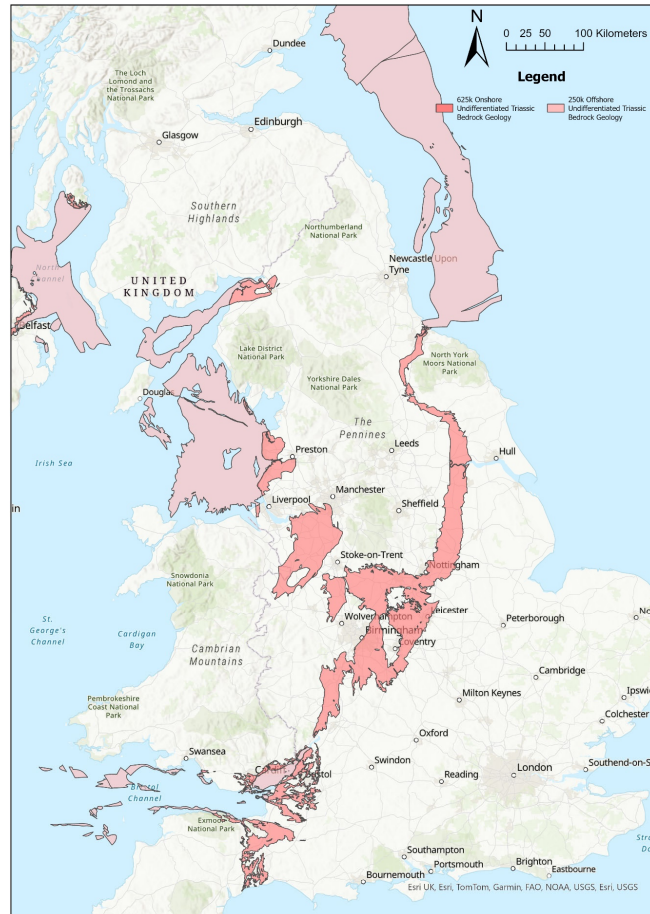
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NAWG 2026

Introduction

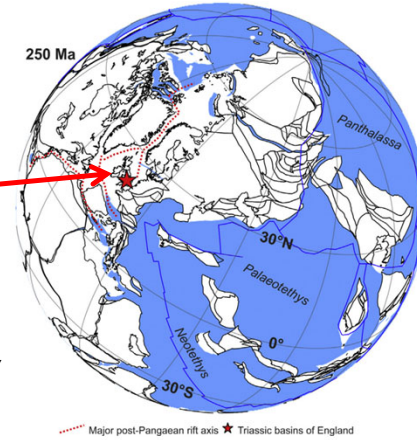
Chrono-stratigraphy (stages)	GROUPS	MMG units and new nomenclature
RHAETIAN	PENARTH GROUP	PENARTH GROUP
NORIAN	MERCIA MUDSTONE GROUP	E BLUE ANCHOR FORMATION
CARNIAN		D BRANSCOMBE MUDSTONE FM
LADINIAN		C ARDEN SANDSTONE FORMATION
ANISIAN		B SIDMOUTH MUDSTONE FORMATION
		A TARPORLEY SILTSTONE FORMATION
	SHERWOOD SANDSTONE GROUP	HELSBY SANDSTONE FORMATION
INDUAN-OLENEKIAN	SHERWOOD SANDSTONE GROUP	WILSMLOW SANDSTONE FORMATION

After Howard et al., 2008

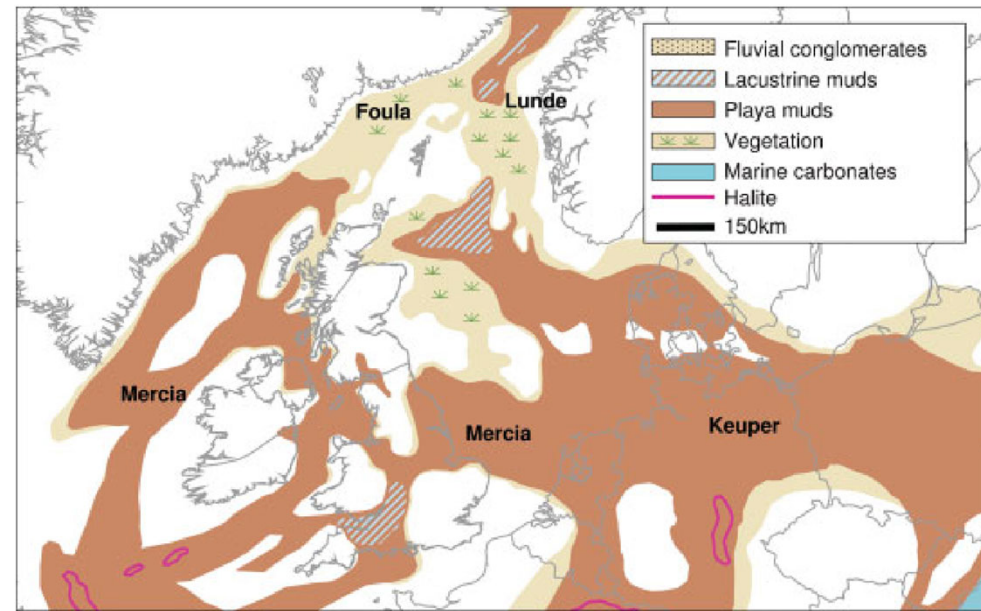


Onshore and offshore distribution of the Mercia Mudstone Group outcrop (red).

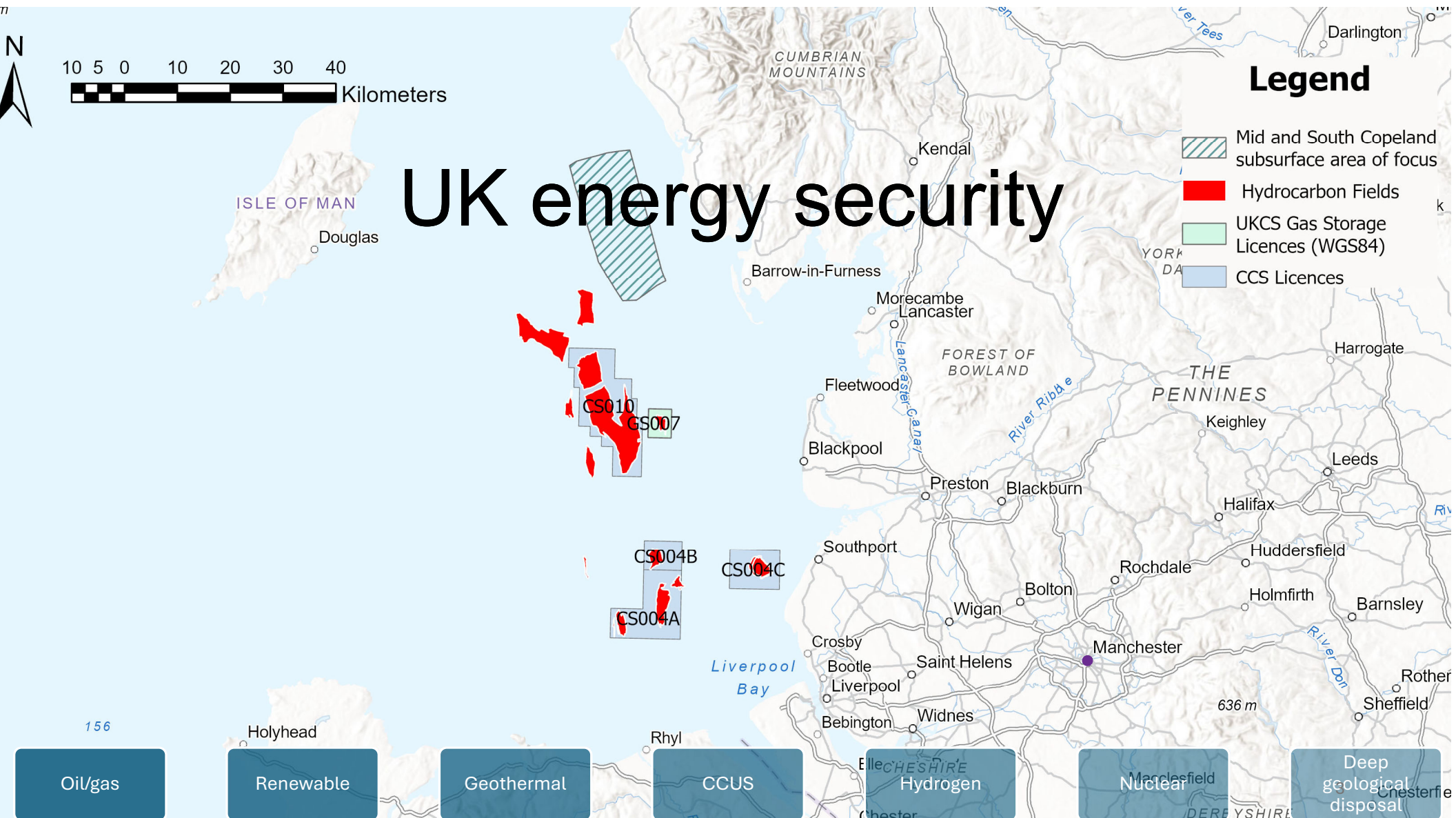
England



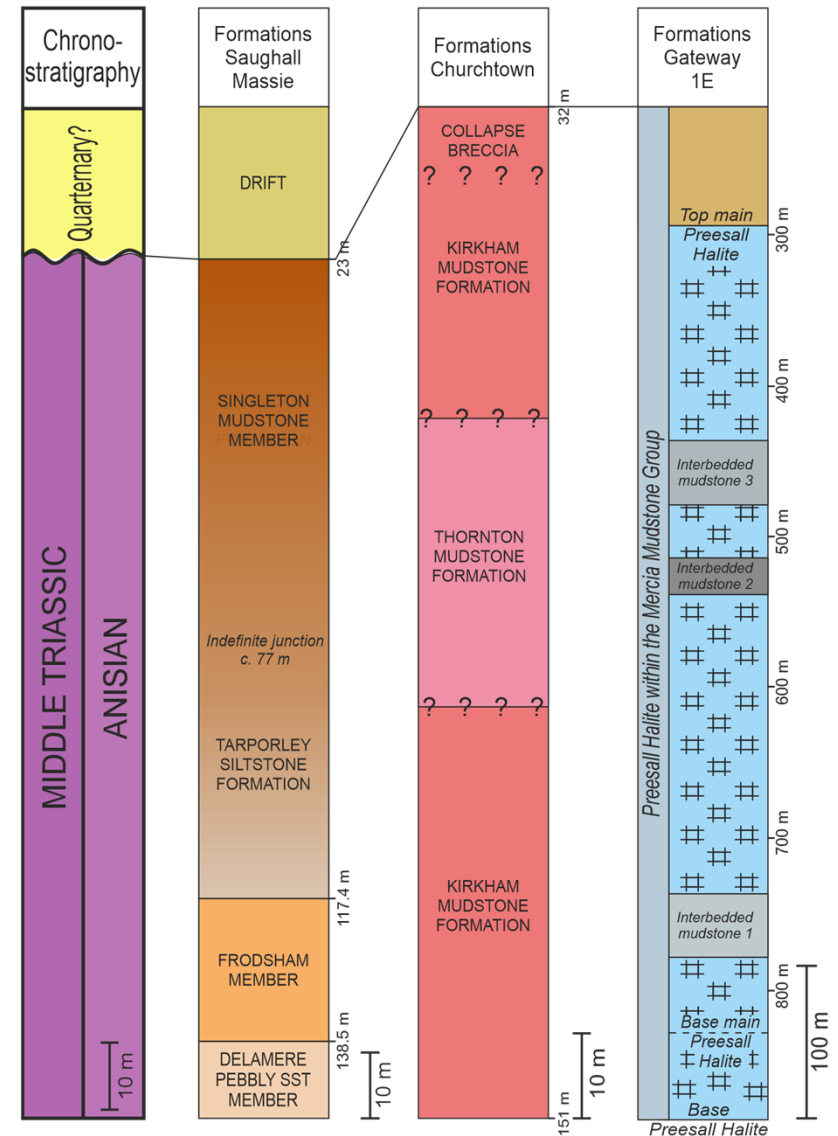
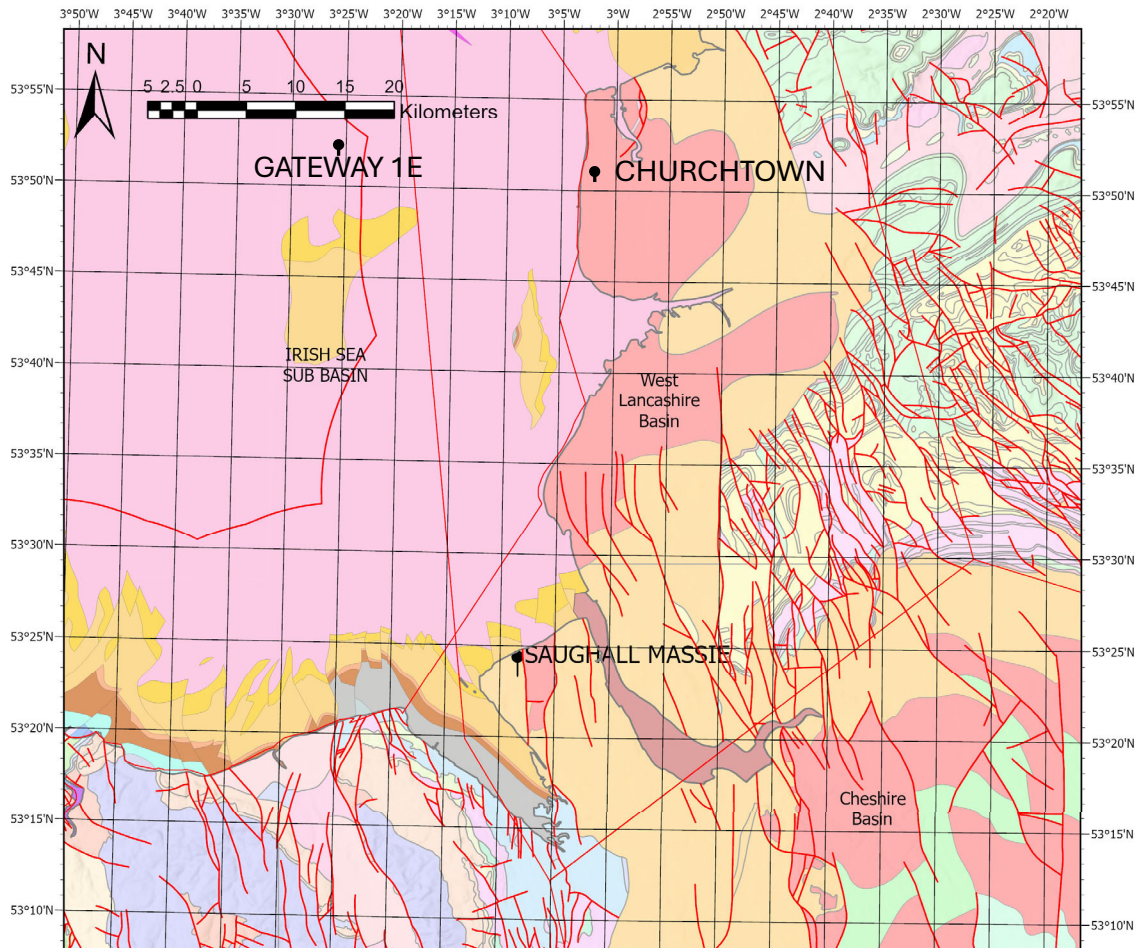
Reconstruction of global plate tectonic setting at the Permo-Triassic boundary (~250 Ma) created by Newell (2018) from Matthews et al. (2016).

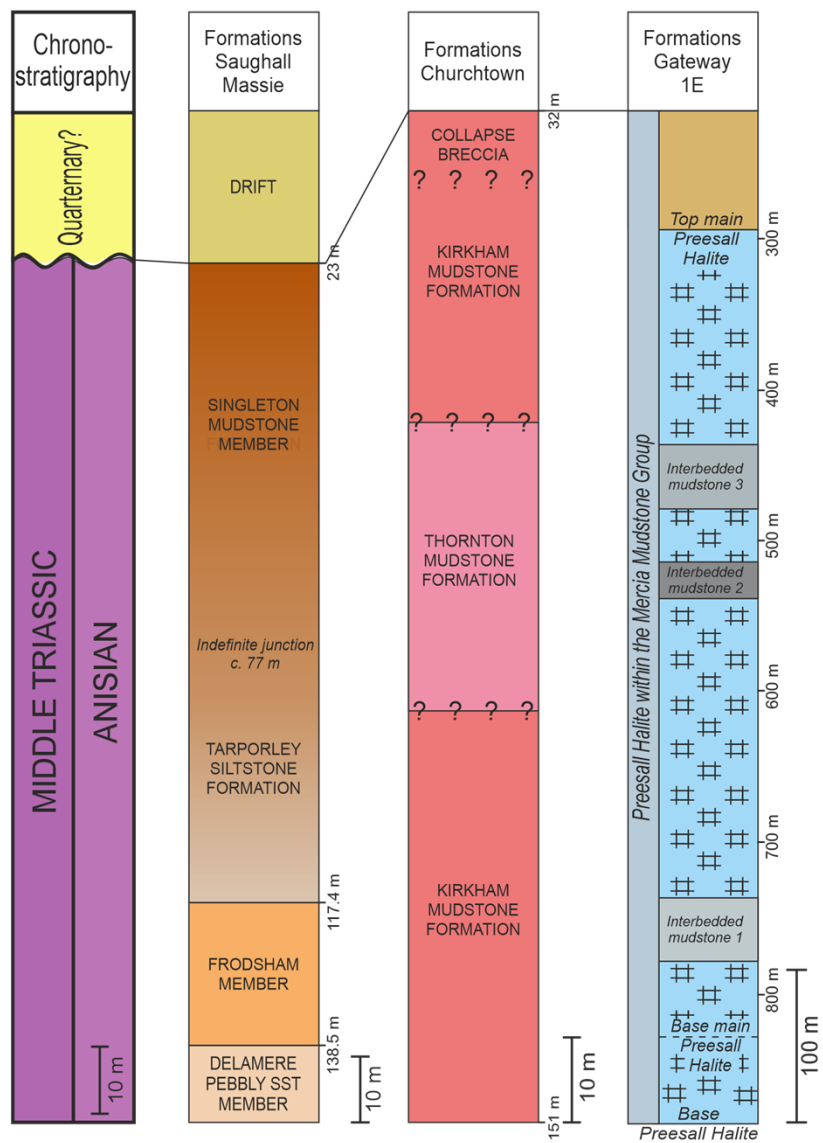


McKie and Williams, 2009 Late Triassic (Norian) palaeogeographic map indicating the extent and distribution of Mercia Mudstone and Keuper Mudstone. Potential host-rocks indicated by yellow star.



Boreholes of study





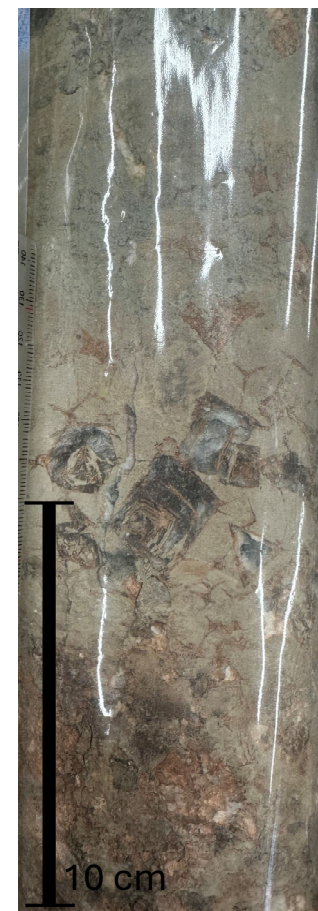
Saughall Massie
Sand-rich



Churchtown
Mud-rich,
brecciated



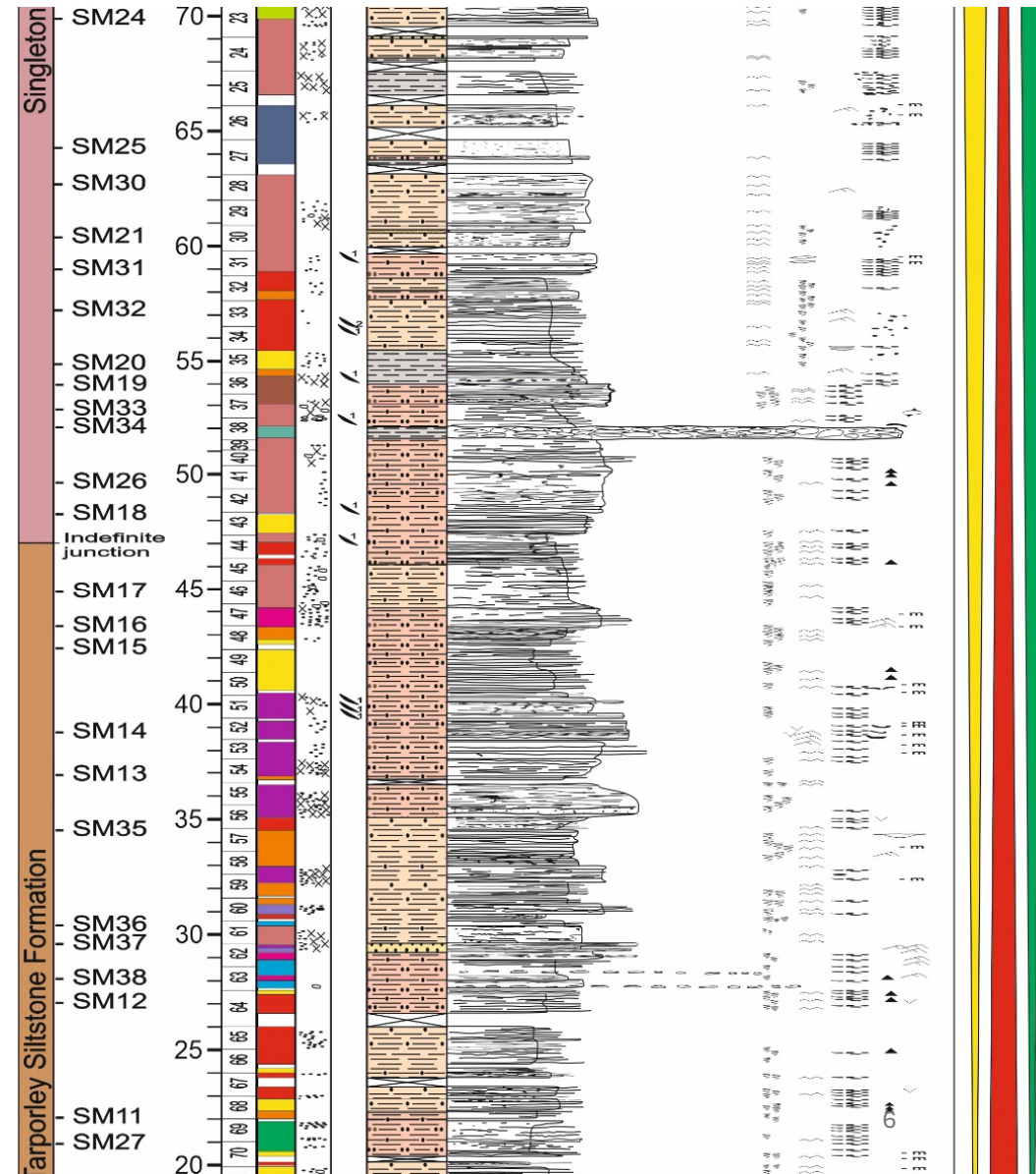
Gateway 1E
Mud-rich, salty



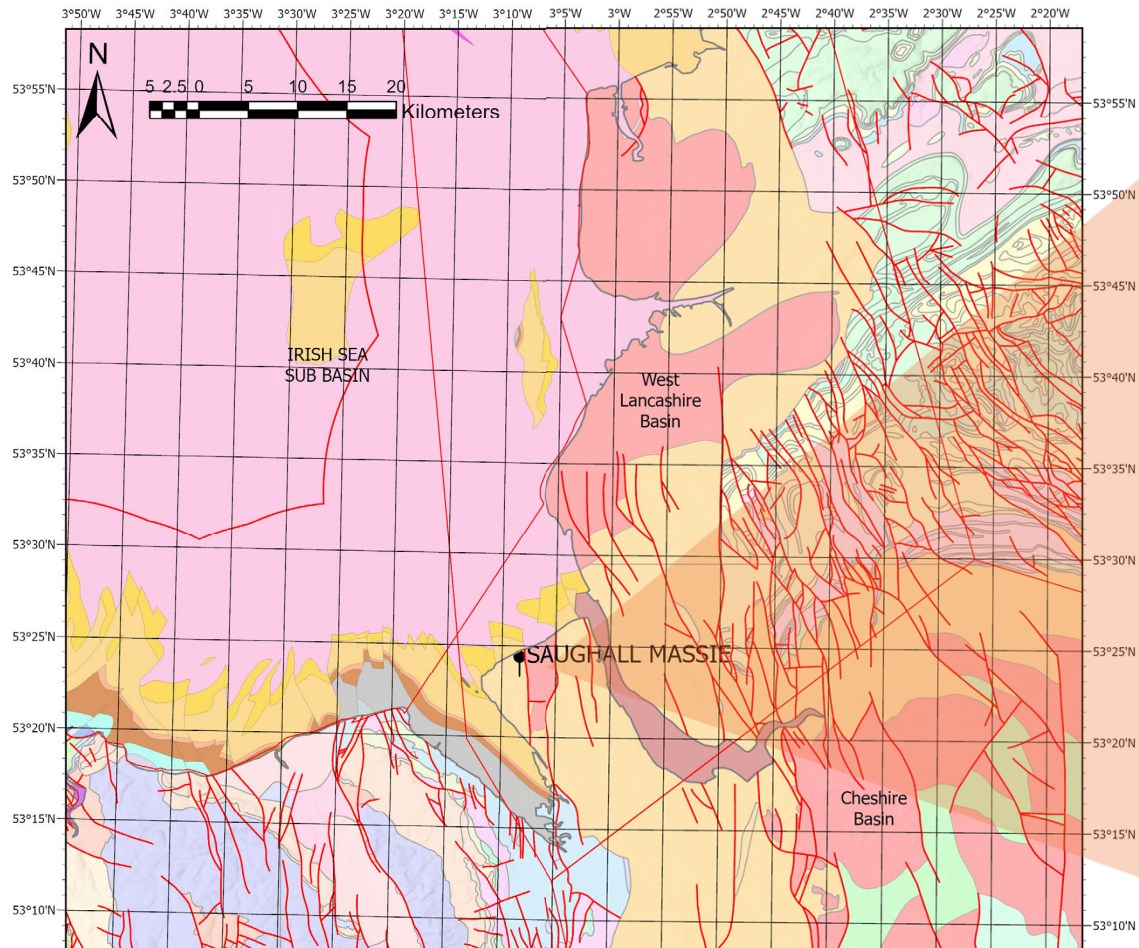
Methodology

Methods:

- Detailed sedimentary logging, of available material from:
 - Saughall Massie OBH core 1:10
 - Churchtown Borehole core 1:10
 - Gateway 1E core description
- Endmember characterisation of a basin-marginal borehole
- Subsampling and subsequent petrographic, XRD mineralogical analyses

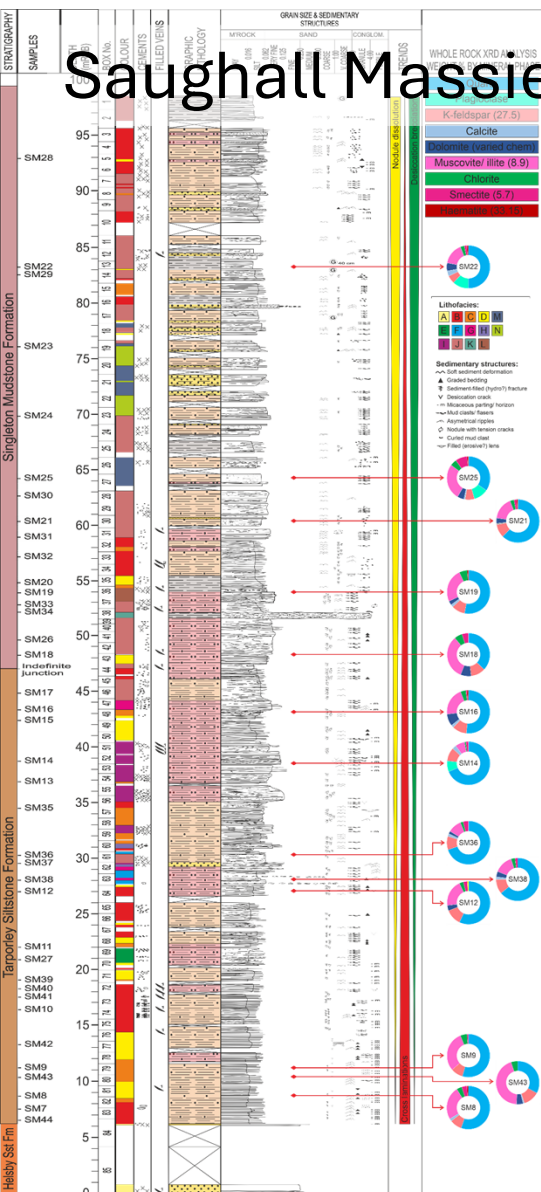


Saughall Massie characterisation

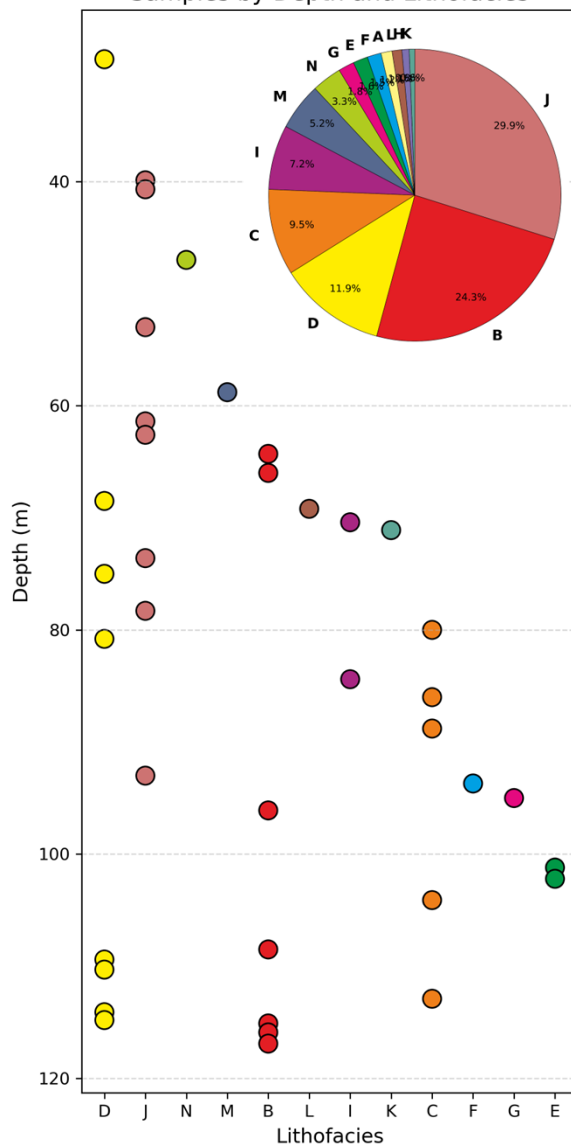


**MMG in Saughall Massie core, Wirral,
Northwest England**

Saughall Massie



Samples by Depth and Lithofacies



Lithofacies A – Massive Sandstone

Lithofacies B – Red/brown laminated sandy siltstone interbedded with mudstone

Lithofacies C – Mixed red/grey laminated sandy siltstone interbedded with mudstone

Lithofacies D – Green/grey laminated sandy siltstone interbedded with mudstone

Lithofacies E – Structureless red siltstone with subsidiary mudstone

Lithofacies F – Cross bedded fine sand with structureless siltstone

Lithofacies G – Green/grey highly disturbed sandy siltstone

Lithofacies H – Red/ brown internally disturbed to massive fine sands to silt-rich

Lithofacies I – Disturbed red siltstone with varying proportions of very fine sand

Lithofacies J – Disturbed to massive red siltstone to very fine sand

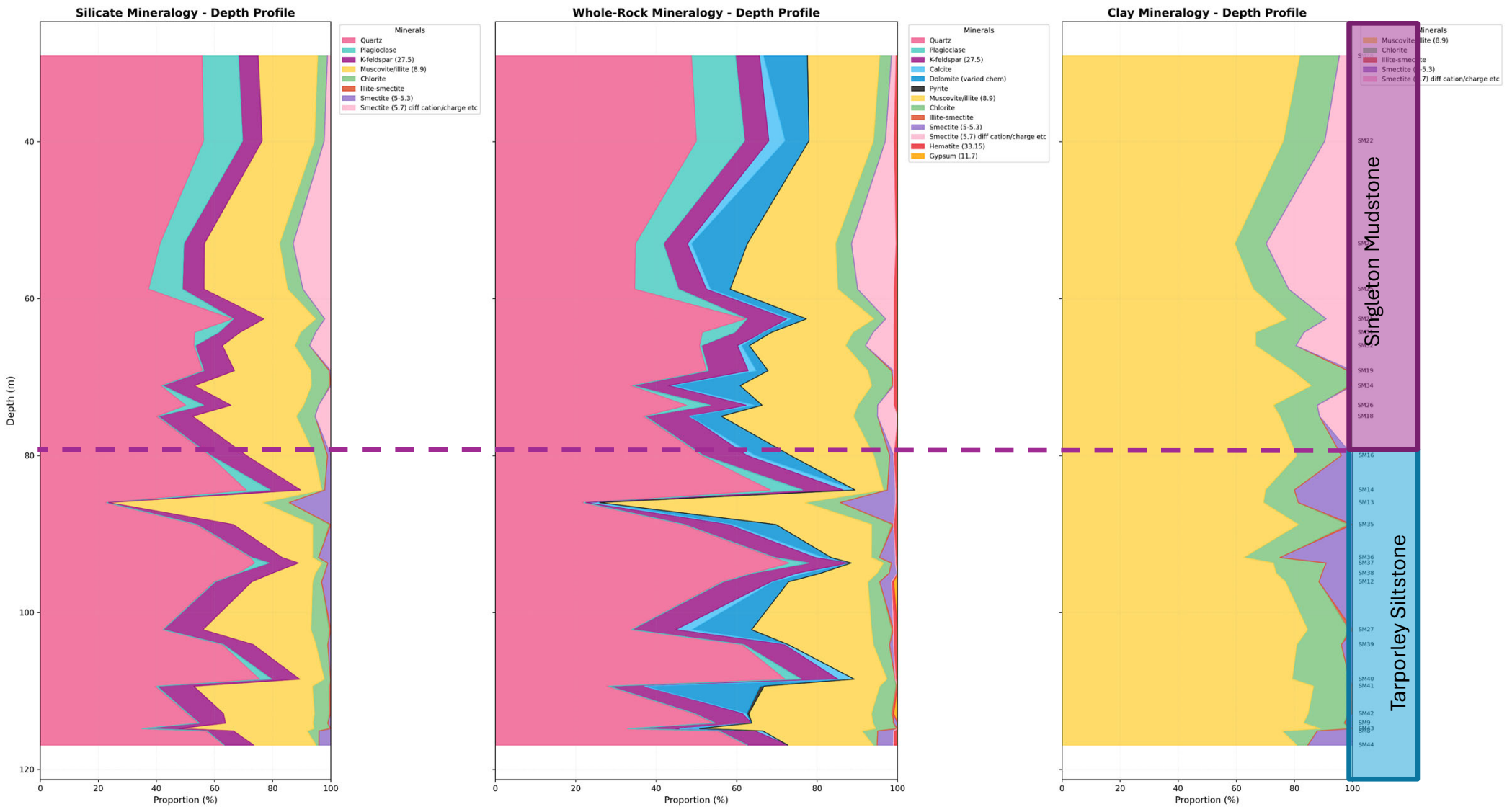
Lithofacies K – Red mud-clast conglomerate

Lithofacies L – Red fine sandstone with mud interlaminae and desiccation cracks

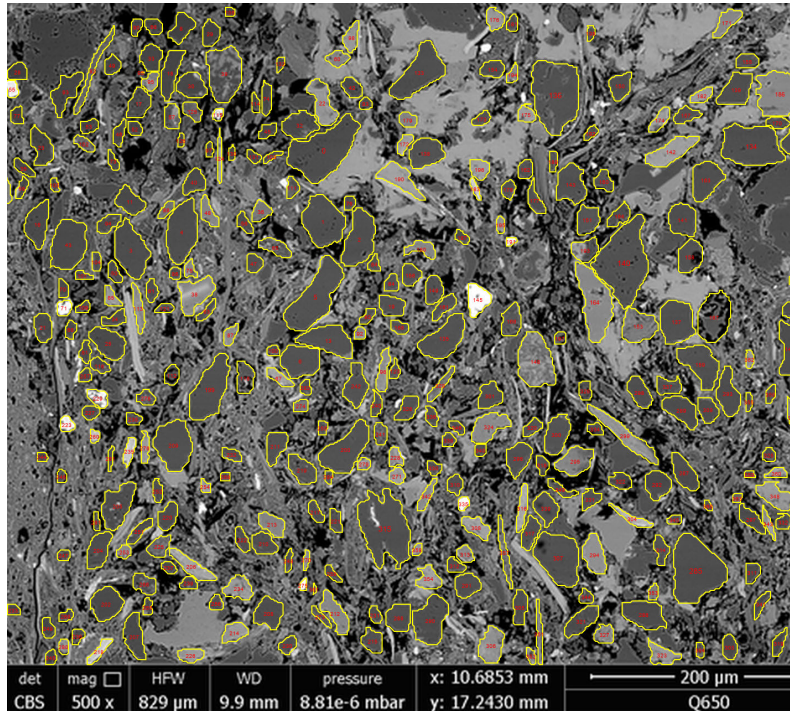
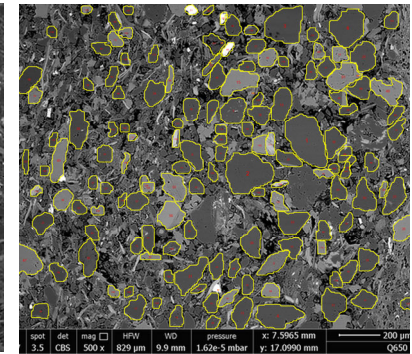
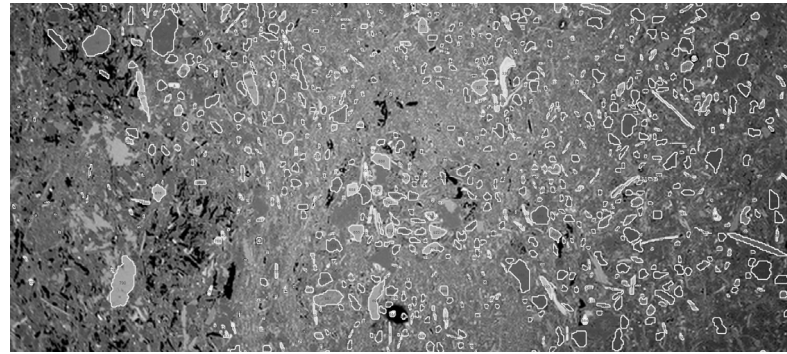
Lithofacies M – Red desiccated silty mudstones

Lithofacies N – Green/grey desiccated muddy siltstone heterolithics

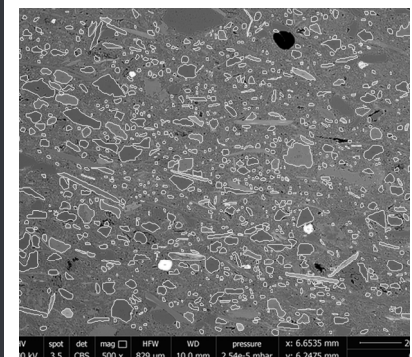
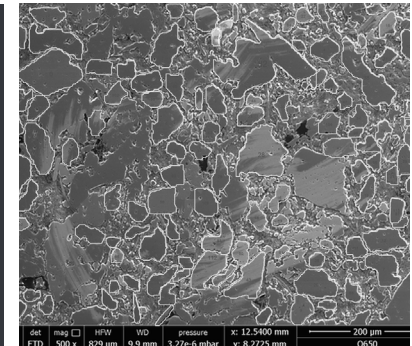




GrainSight

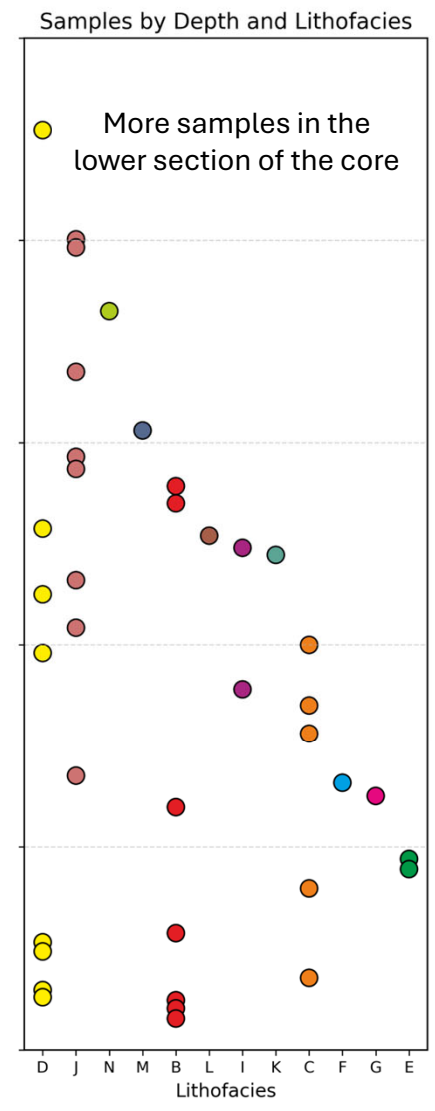
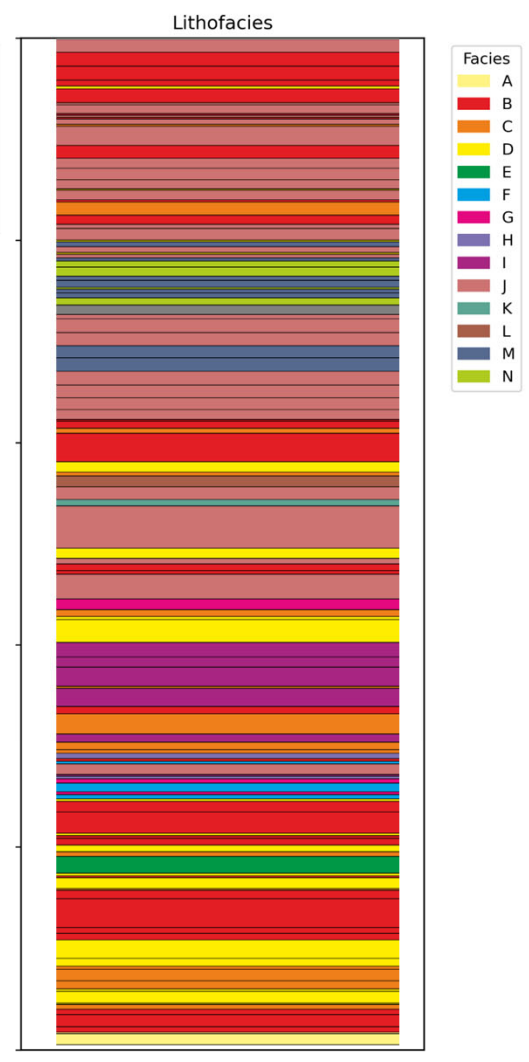
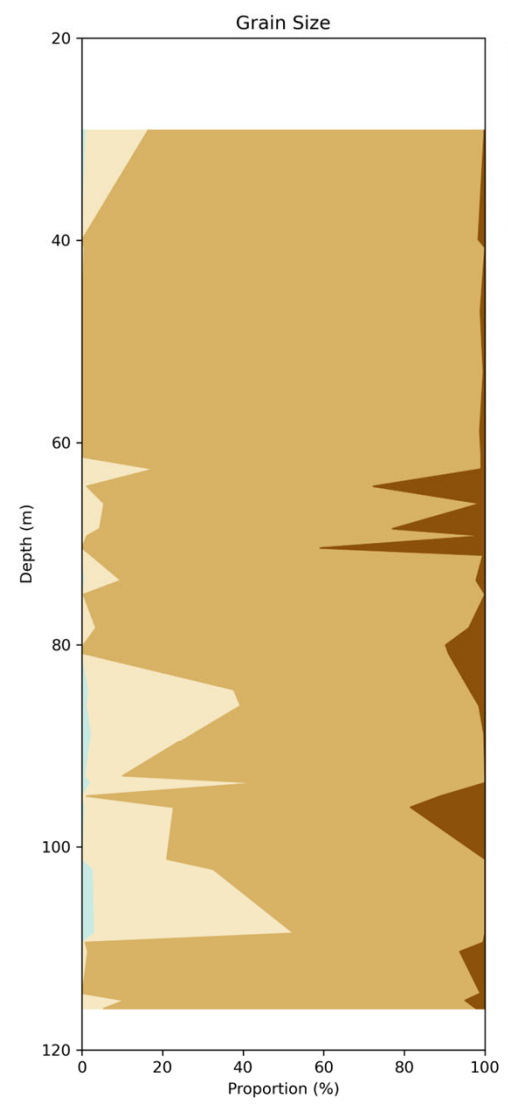


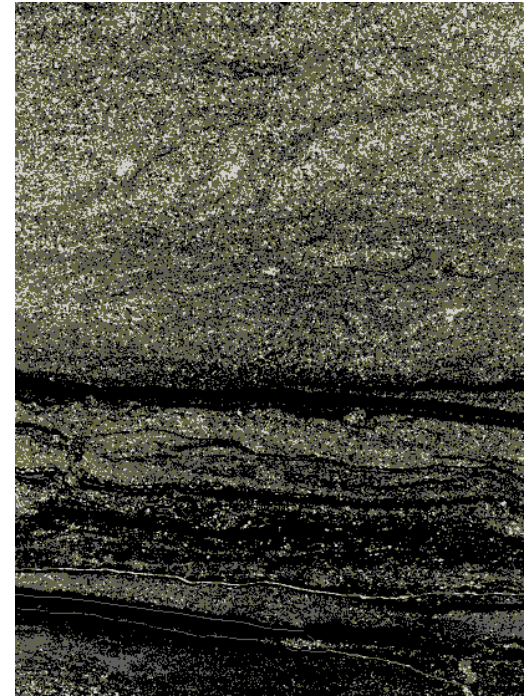
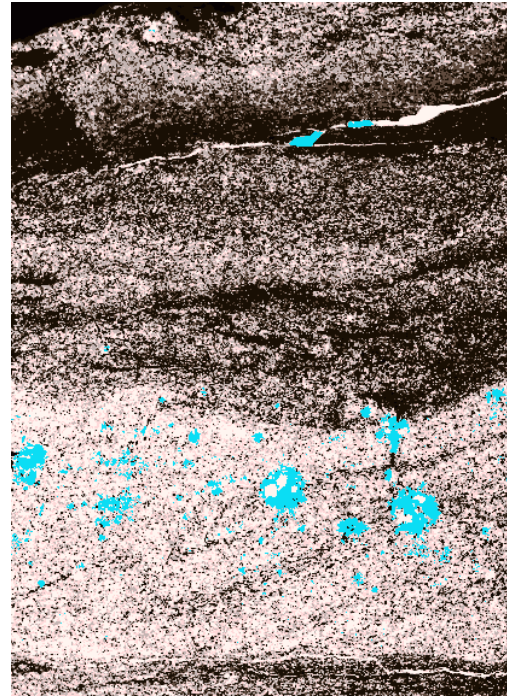
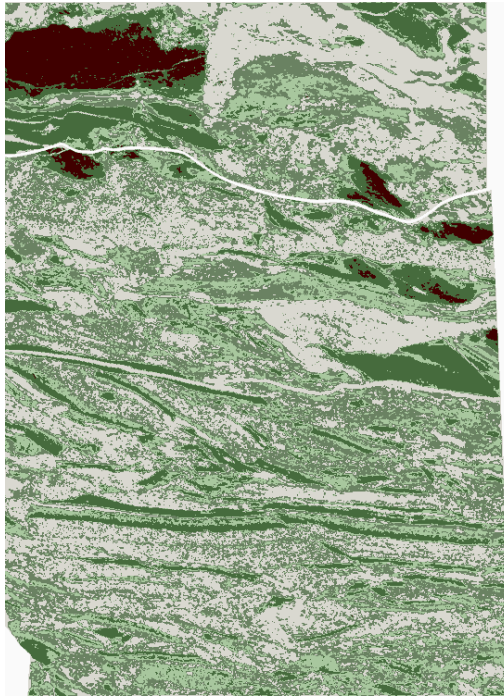
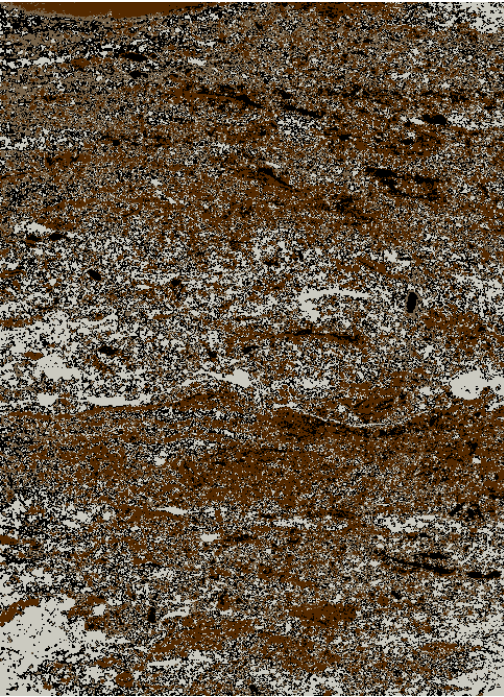
- Run software on all images of each thin section, 25-40 images of each thin section,
- Quality check that it is identifying real grains, remove those touching the borders of the image.
- Extract the information and build it into the dataframe.
- Run comparative analysis, build graphs, run statistical tests.



Discrepancy in the grainsight software under recognising finer grains. XRD confirms clay mineralogies are more abundant in the upper sections of the core.

More very fine sand and fine sand identified in the Tarporley Siltstone Fm





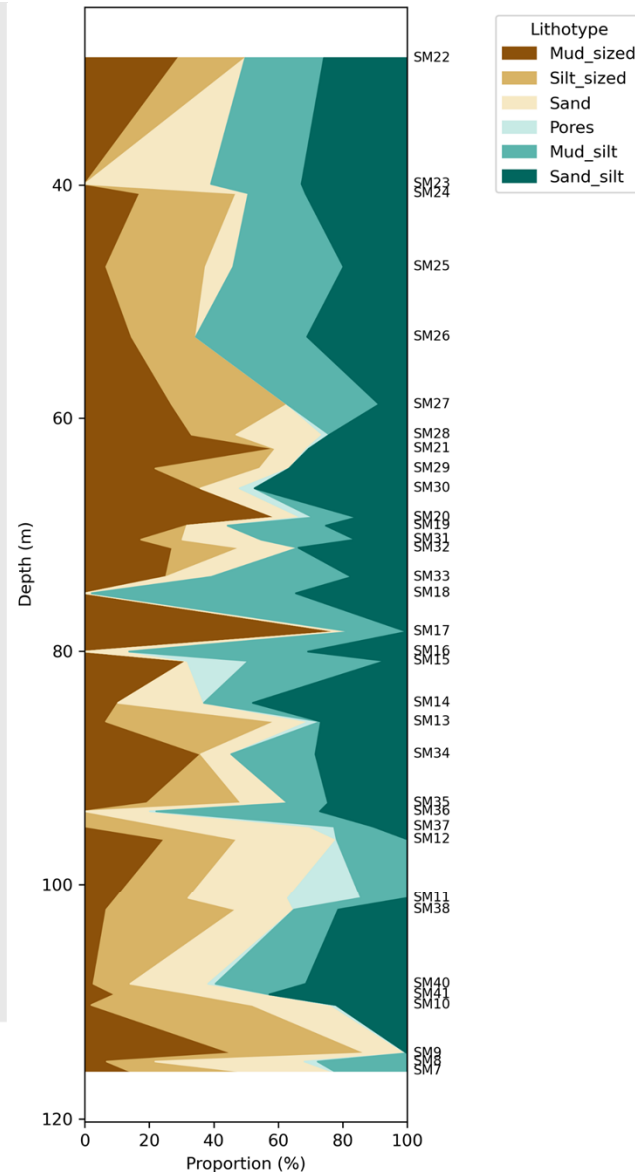
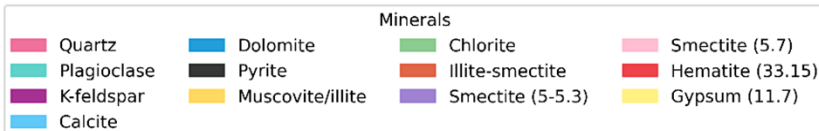
Petroseg

- Scanned all the thin sections
- Ran them through this software, supervised machine learning
- It uses colour to segment the images
- QC the data, combine some of the thresholds and interpret what lithotype they represent

Petroseg

Mix of qualitative description of relative abundance of mud, silt, or sand that is then quantified into a percentage area of the thin section.

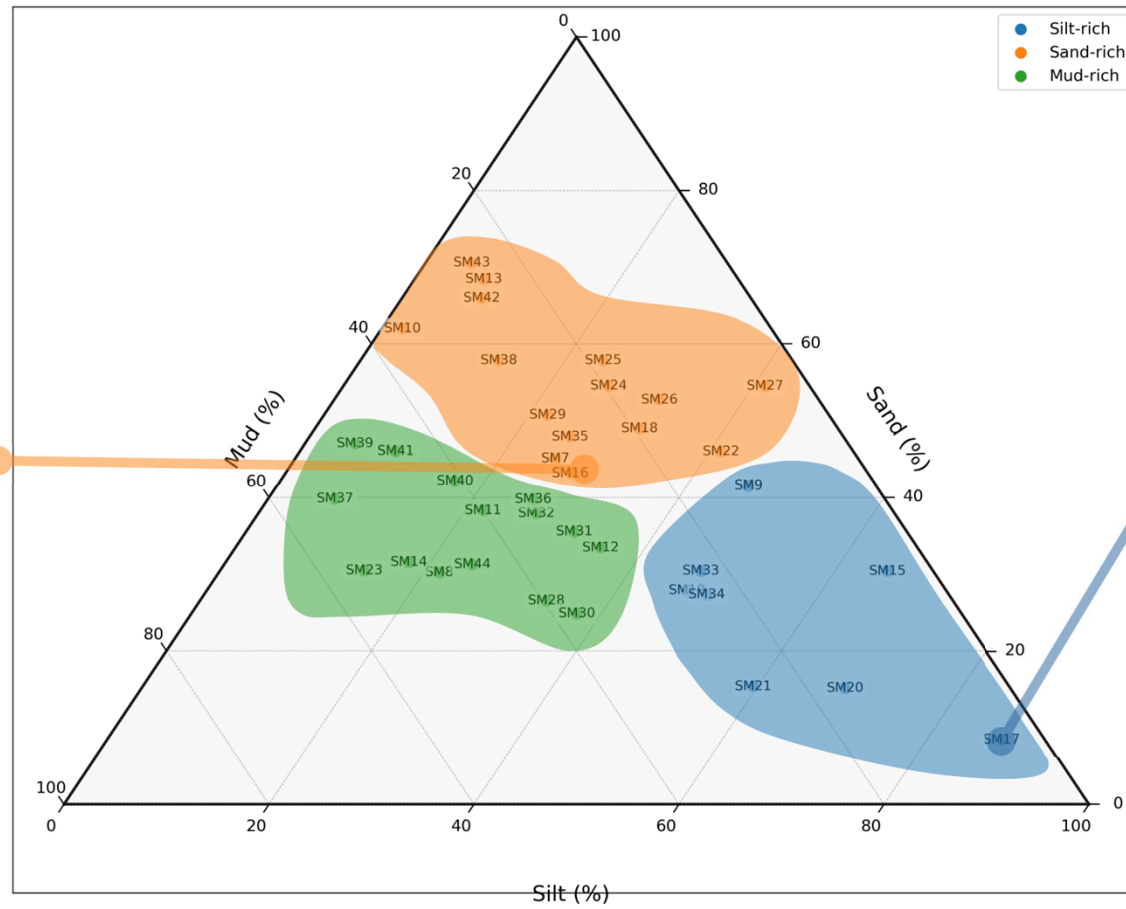
- Follows trend of more sand and sandy silts in the Tarporley
- Greater abundance of pores in the Tarporley Siltstone
- Greater abundance of mud-sized and silt-sized material into the Singleton Mudstone



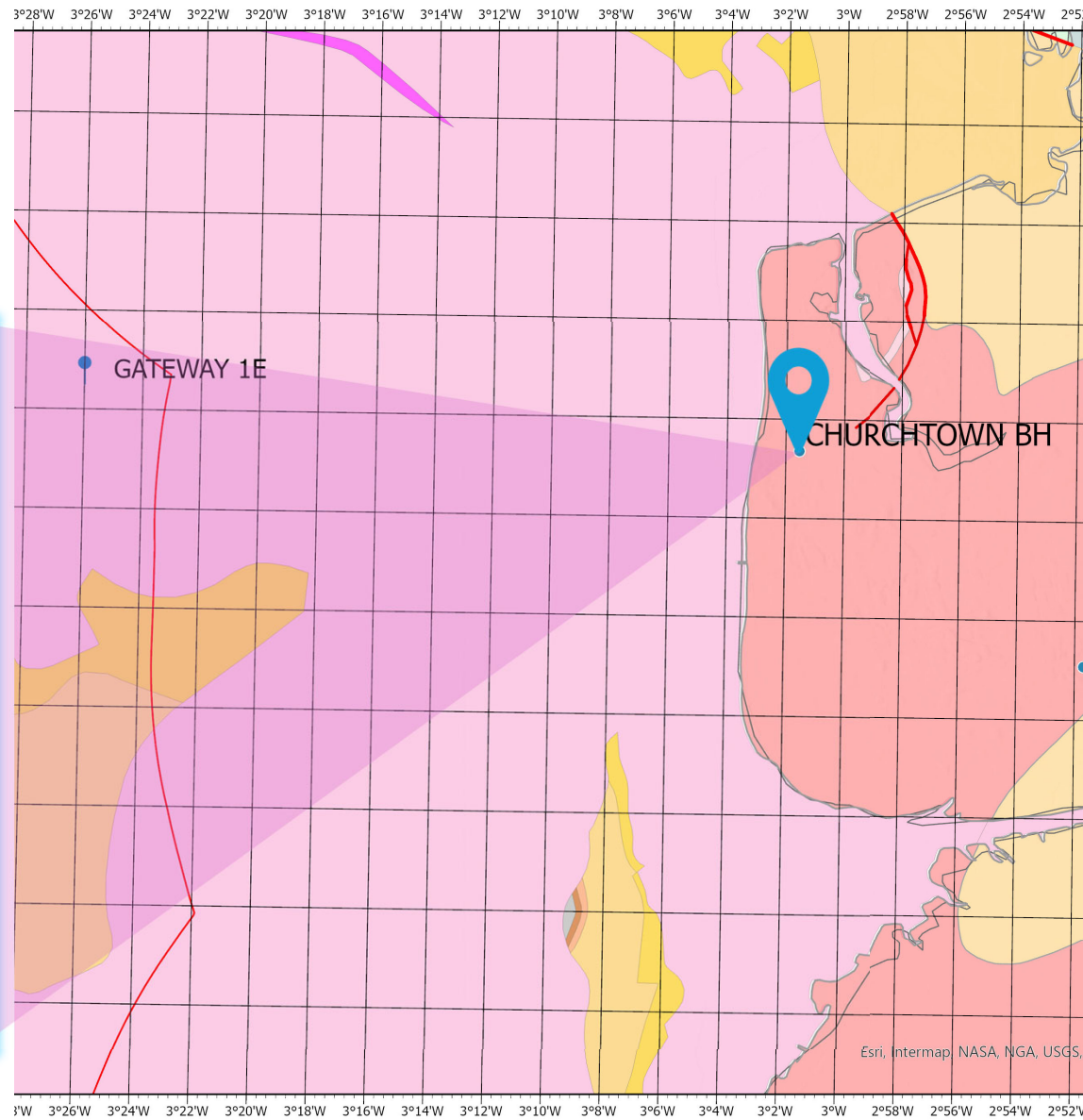
Sediment Ternary Diagram with K-means Clustering

SM16

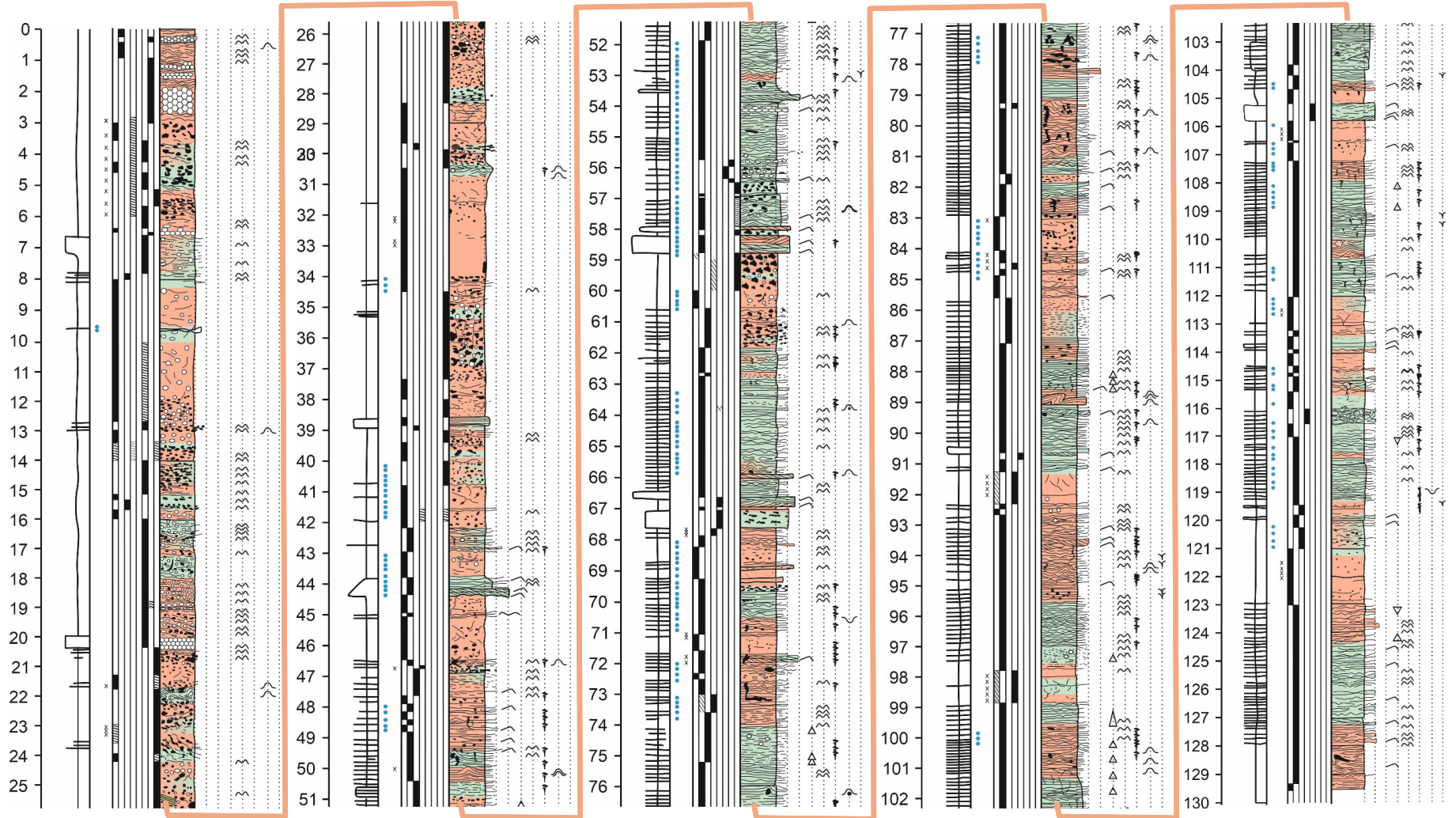
SM17



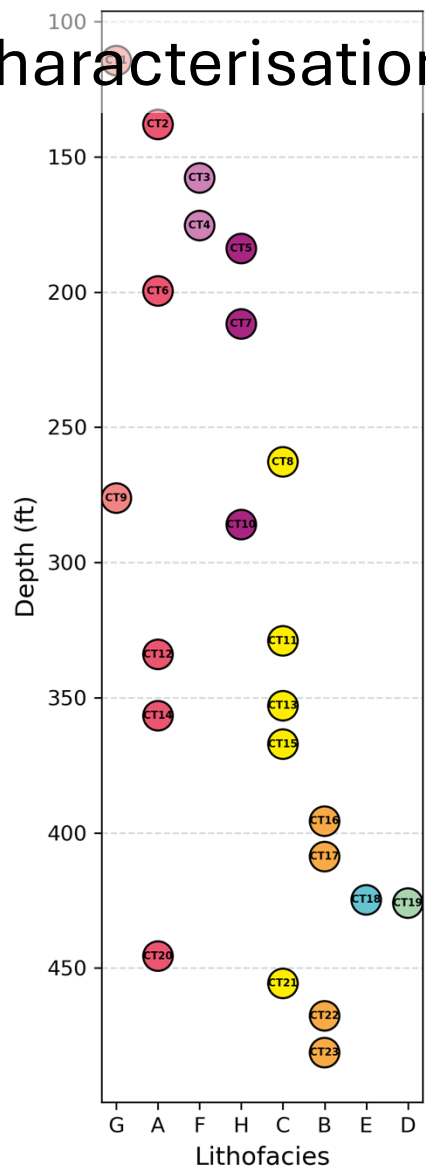
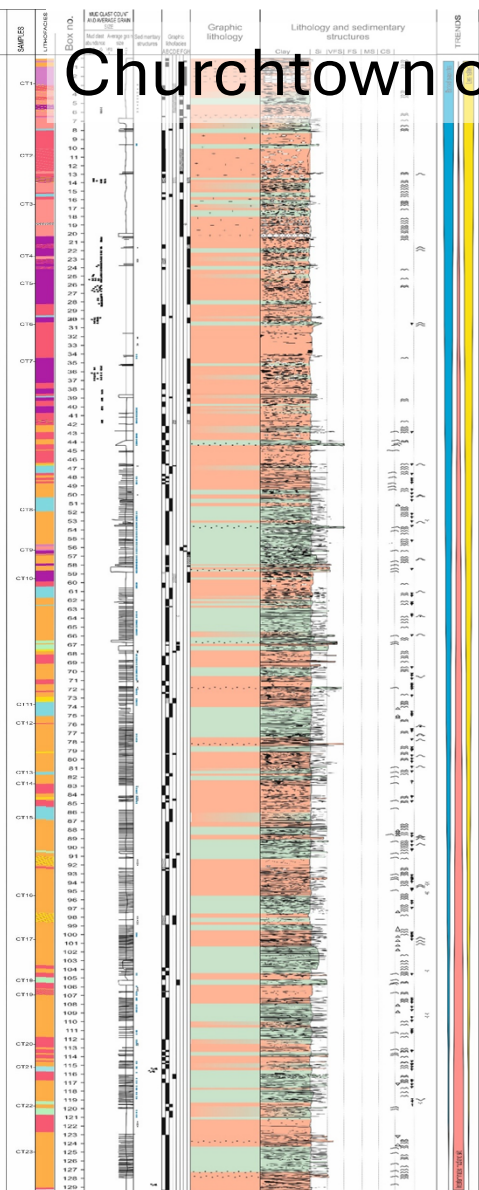
Churchtown borehole



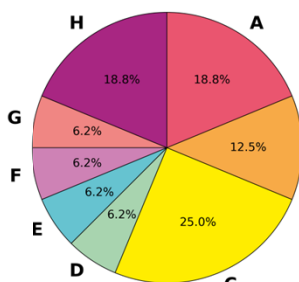
Churchtown graphic sedimentary log:



Churchtown characterisation

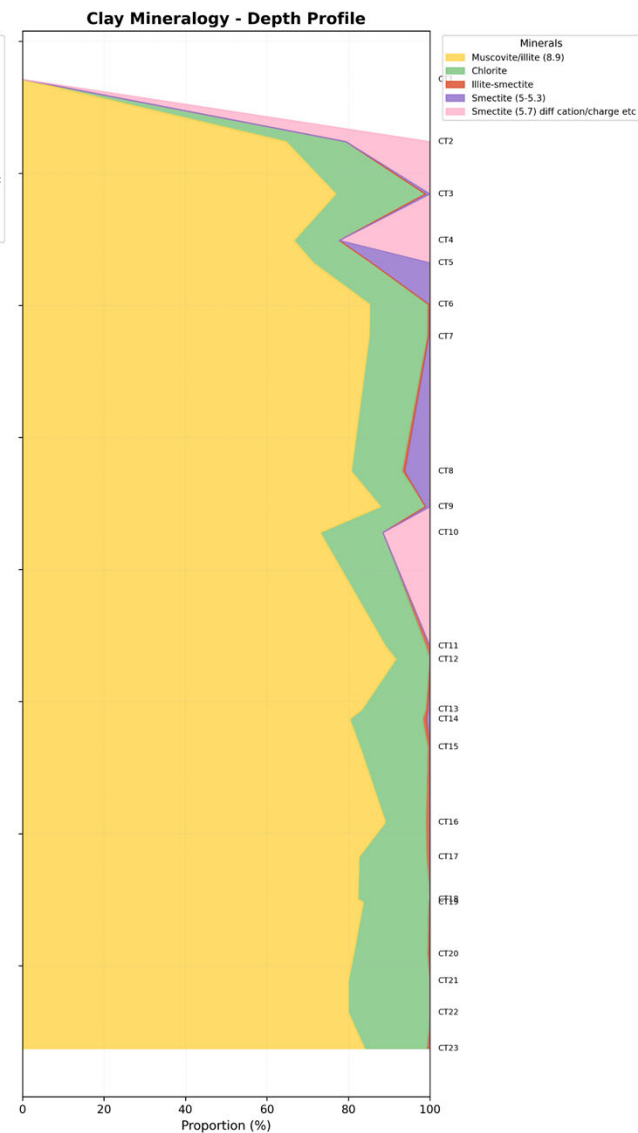
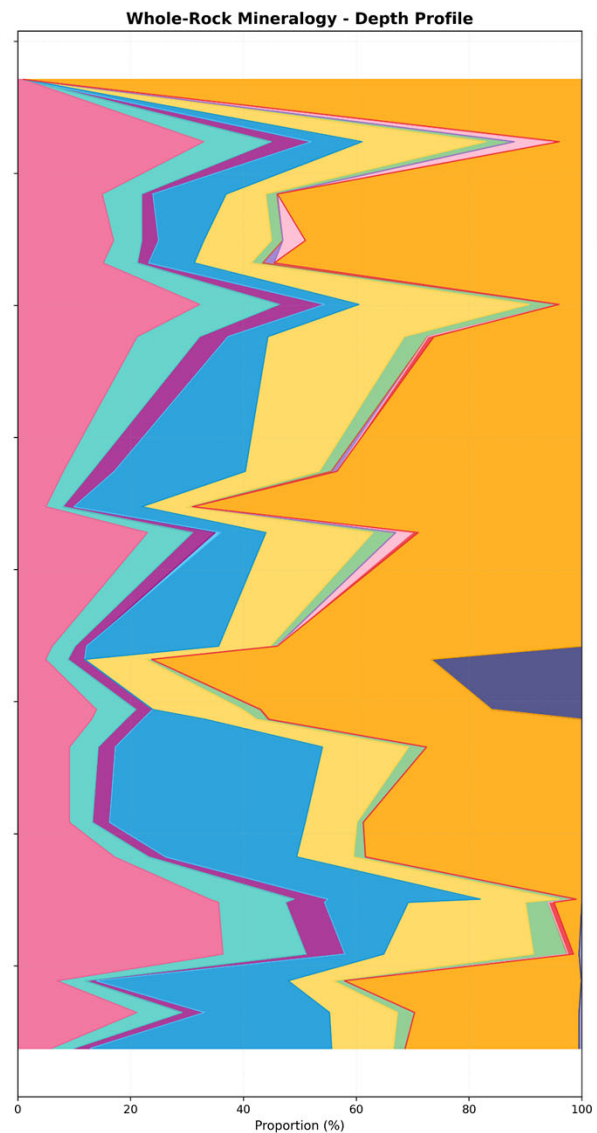
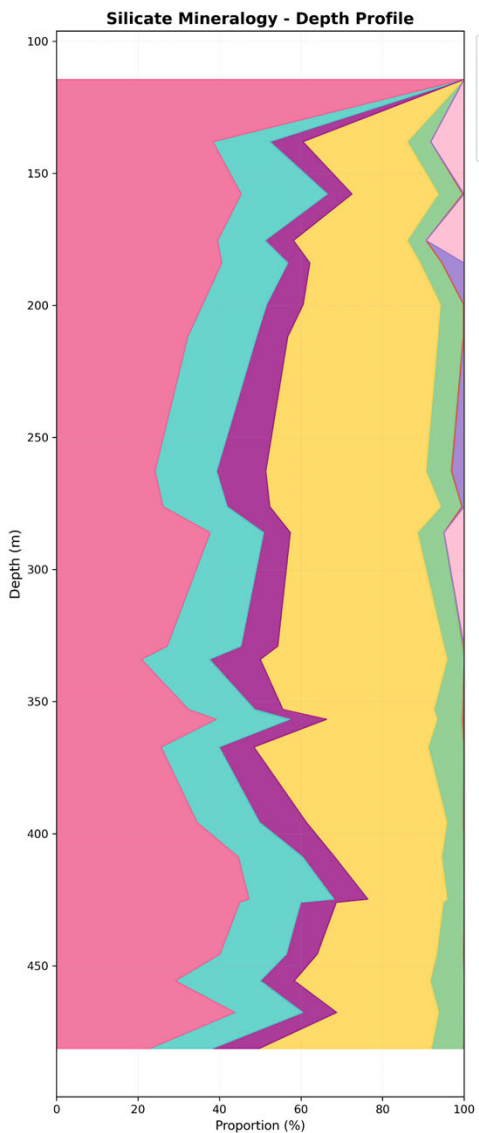


Lithofacies Distribution in Shortest Interval



- Lithofacies A** – Structureless reddish brown or greenish grey mudstone with gypsum nodules and veins
- Lithofacies B** – Interlaminated grey and pale brown or red and pale brown mudstones and siltstones with gypsum veins, current ripple laminations, desiccation cracks, mud clasts, and pseudomorphs after halite*?
- Lithofacies C** – Disturbed, poorly laminated red or grey mudstones/siltstones with gypsum nodules, veins, and mud clasts
- Lithofacies D** – Brecciated material, potentially by drilling
- Lithofacies E** – Structureless cemented grey siltstone
- Lithofacies F** – ‘Haselgebirge’ lithology of mudstone supporting evaporite clasts, halite crystals set within a red mudstone matrix
- Lithofacies G** – Bedded salt with thin mud partings
- Lithofacies H** – Mud clast breccia supported by mud matrix

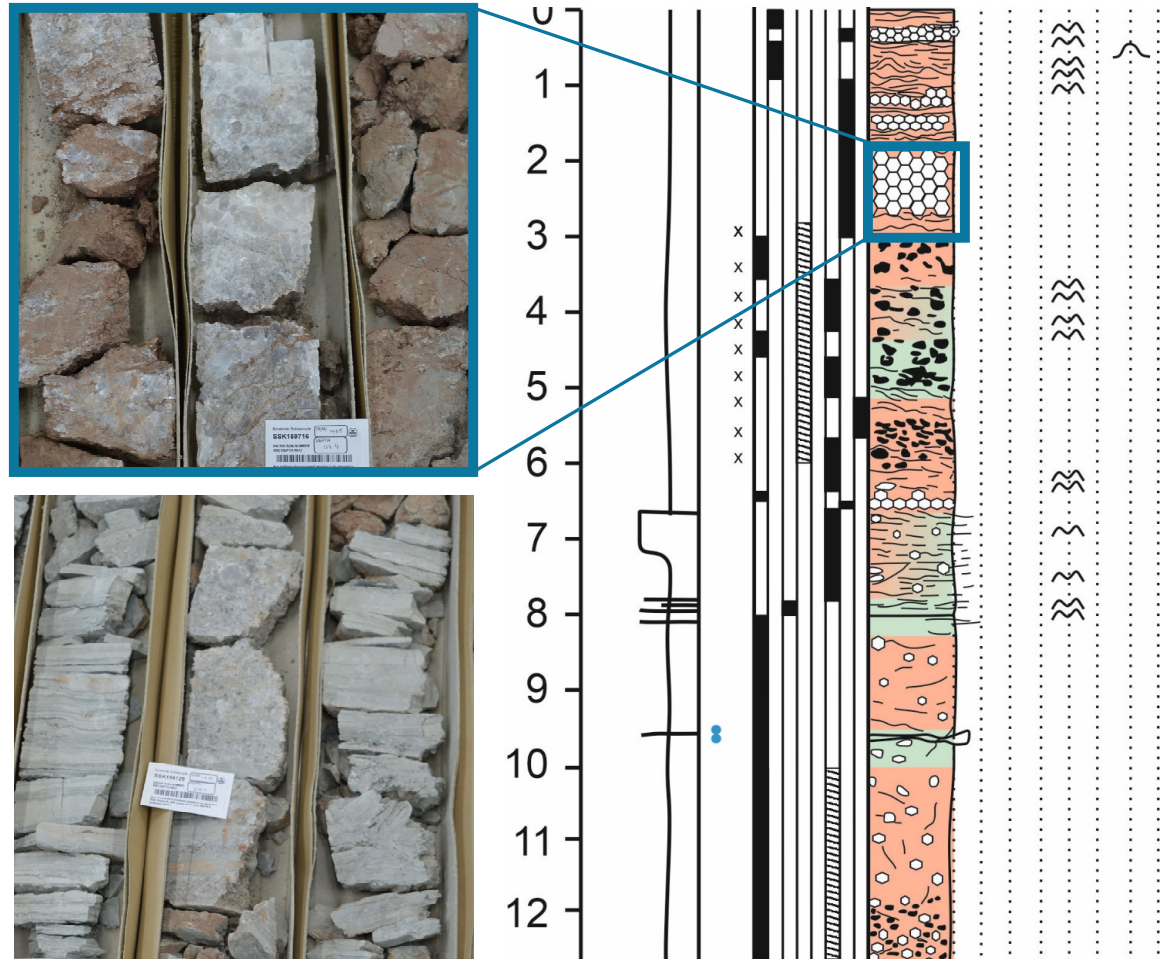




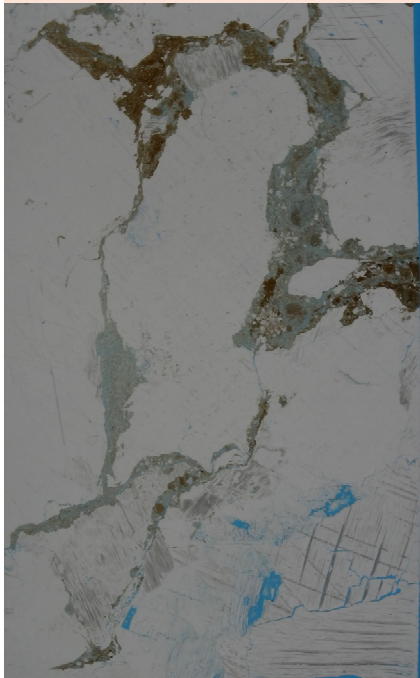
Evaporites

- Gypsum common as veins and nodules throughout.
- Dolomite cement.
- Halite common in lower sections of core.

Interbedded with thin partitions of mud or thick bedded. They also form hasilgebirge textures with mud clasts and mud drapes throughout.



Heterogeneity in the Churchtown core



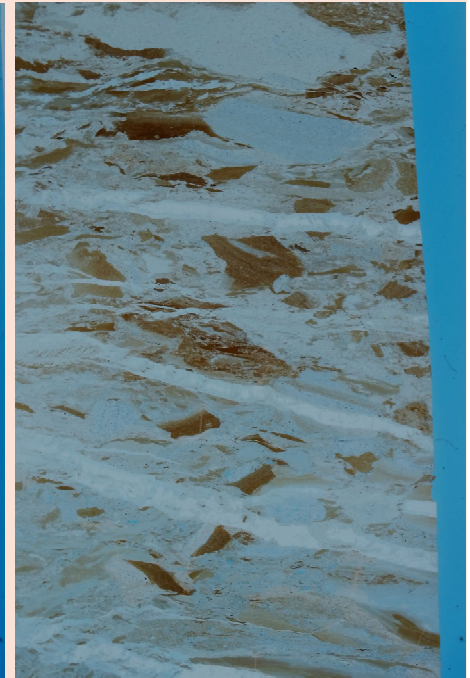
- Evaporites
- Gypsum-rich
- Altered zones



- Brecciated mud
- Rounded clasts
- Evaporites

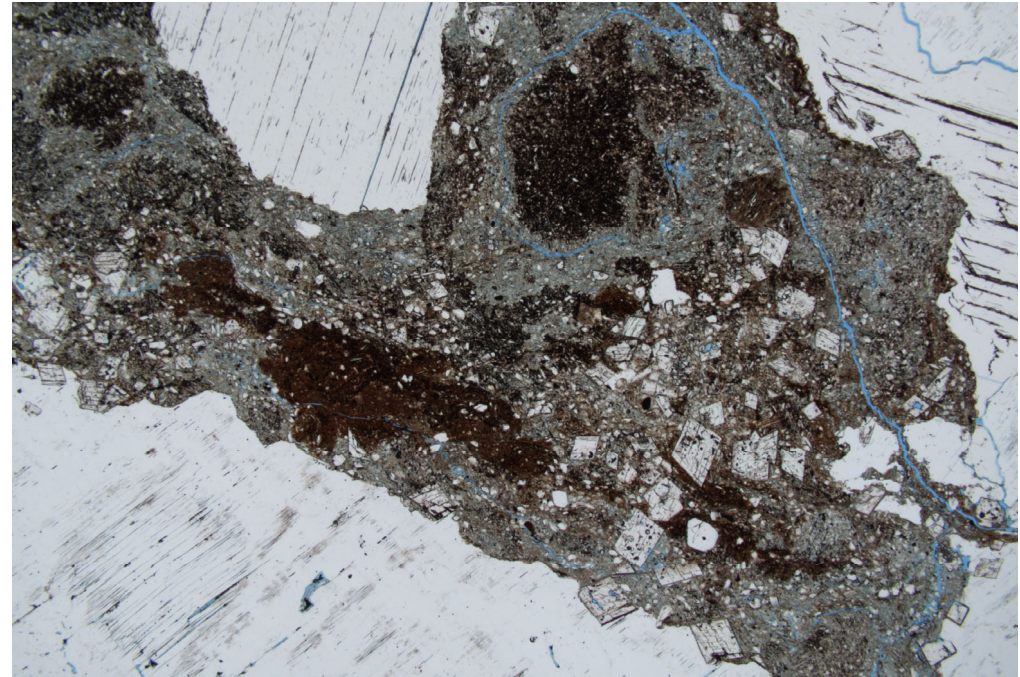


- Evaporite veins
- Gypsum-rich
- Laminations and mm-scale beds

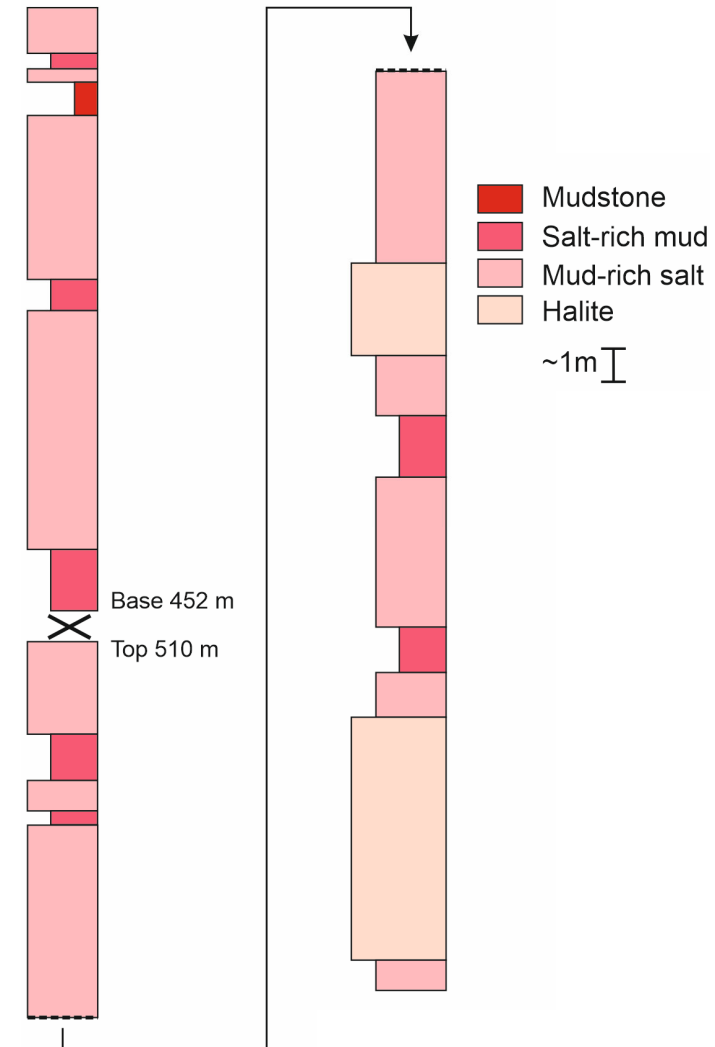
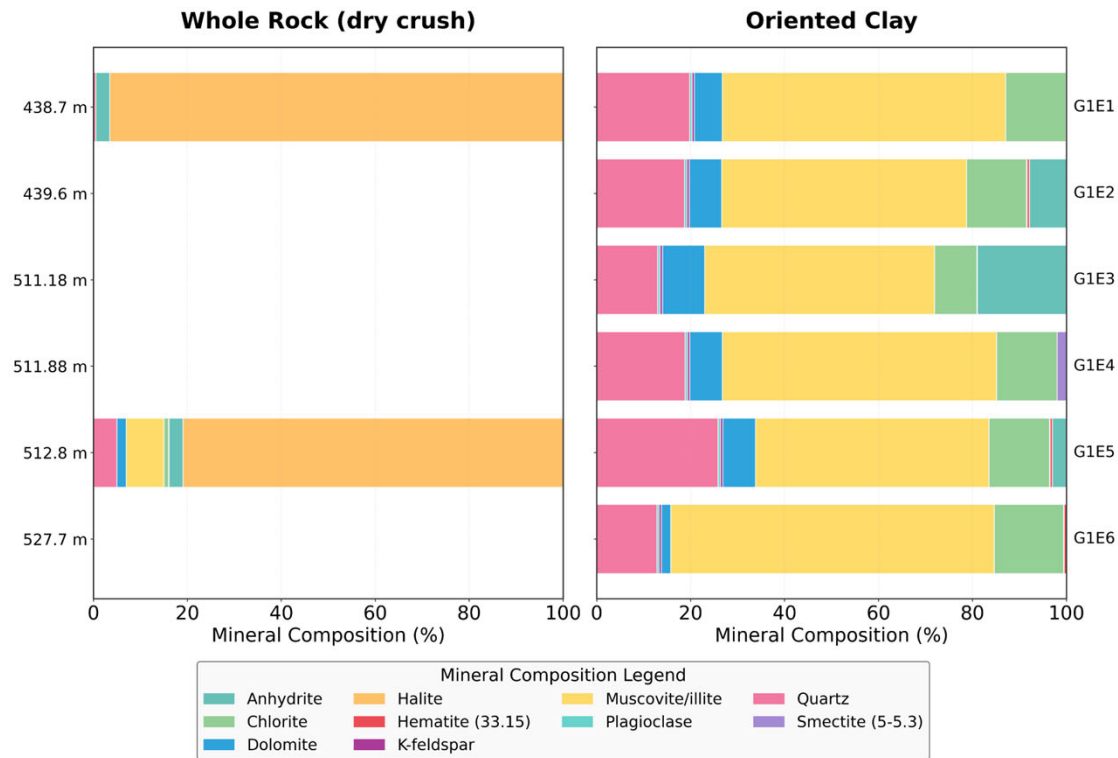


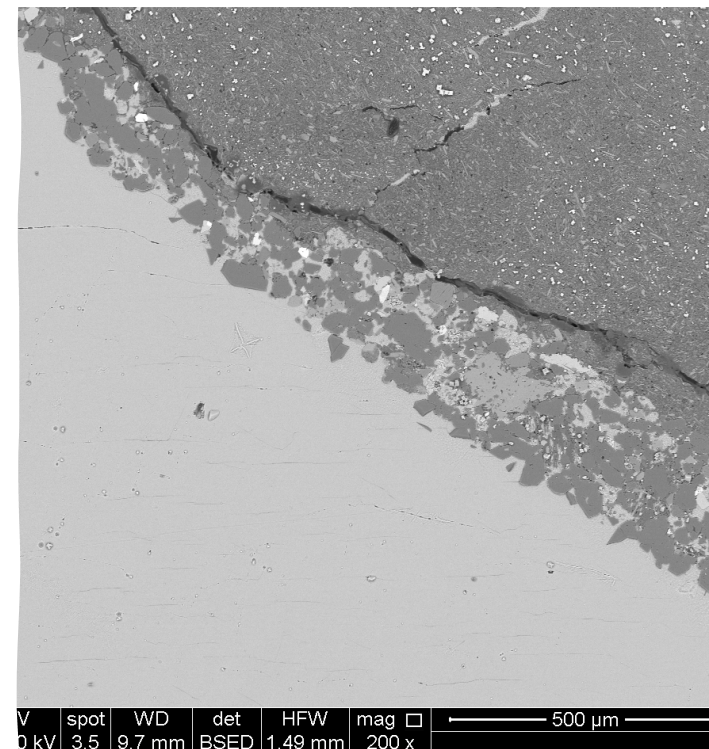
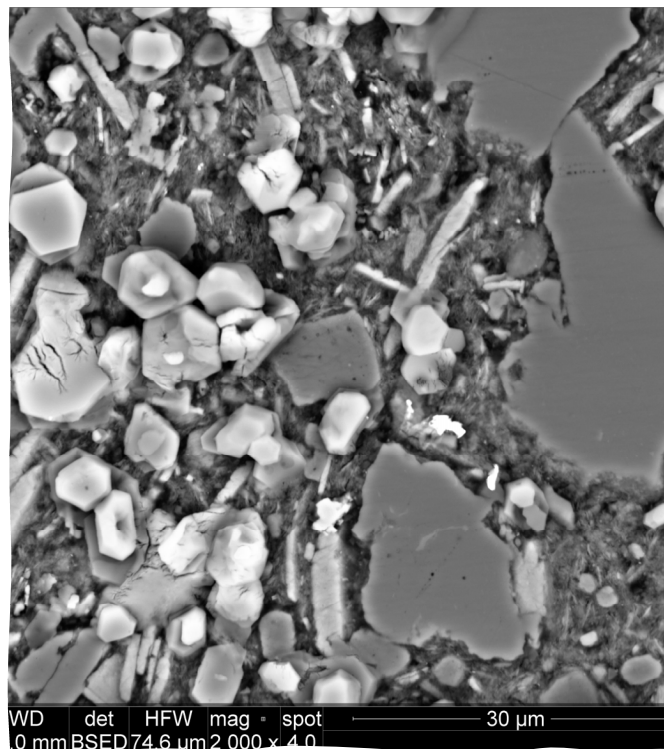
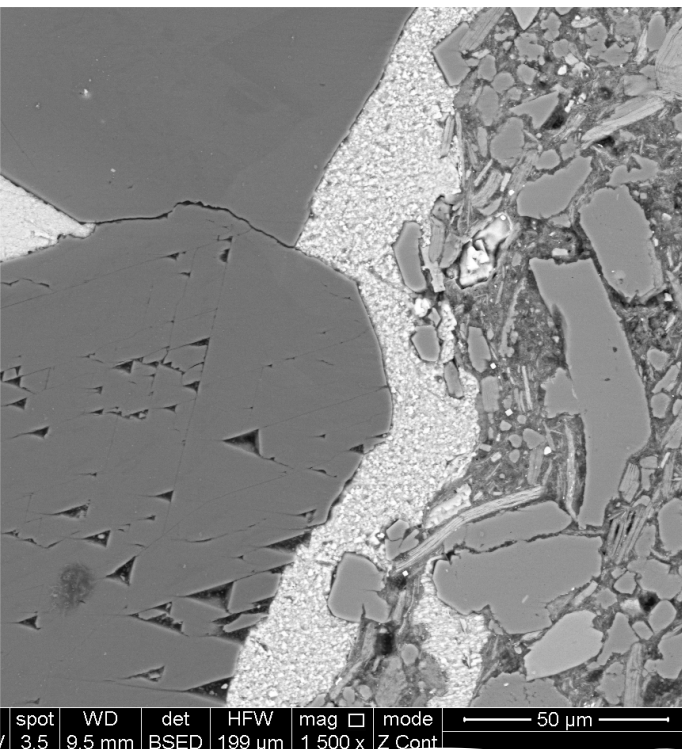
- Evaporite veins
- Angular brecciated mud clasts
- Altered zones

Optical microscopy of Churchtown



Gateway 1E

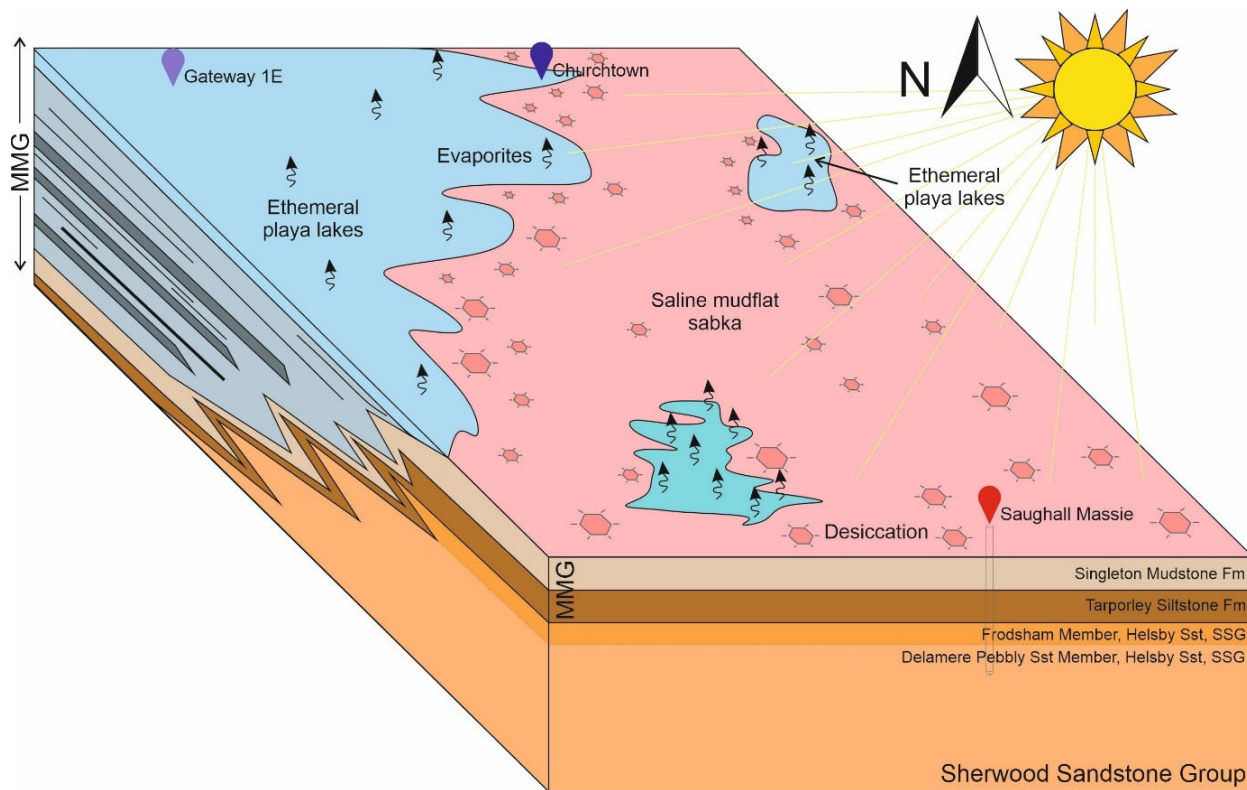




Gateway 1E

- Interesting halite crystal-mud interfaces lined with coarser grains at contact.
- Larger crystals and fine crystalline.

Summative diagram to show distribution of boreholes



- Thicker section of MMG depositing in the east Irish sea due to structural thickening, thick evaporite sequences.
- Churchtown has some salty influence where Preesall deposited and was later dissolved syndepositionally and post-depositionally by glacial waters.
- Saughall Massie was deposited with more fluvial influence, higher proportion of sand intervals and no evaporitic sequences.

Conclusions

The Mercia Mudstone Group is heterogeneous in the northwest

The Saughall Massie core reveals complex, heterogeneous lithofacies with interbedded silts and particularly sands at multiple scales.

The Churchtown core reveals complex, though thicker mud-dominated sections with brecciation and evaporite intervals.

The Gateway 1E core is highly evaporitic with thicker mud-dominated sections and little sand.

Understanding the complexity and characteristics is important for geological disposal so that site descriptive models are built on site-relevant information to predict behaviour of the geological disposal facility.

Interpreting depositional environments remains challenging due to heterogeneity and diagenetic overprint.

MANCHESTER
1824

RIPPLES

United Kingdom
National Nuclear
Laboratory

WATER ESCAPE?

RIPPLES

MM-SCALE NODULES

RIP-UP MUD?

UNIVERSITY OF
LIVERPOOL

MUD CLASTS, REDUCTION

LENTICULAR BEDS

LENTICULAR BEDS

GRANULE BRECCIA

RIPPLES

CROSS LAM

BURROW?

Thank you!

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DESICCATION CRACKS

MICACEOUS LAYER

MICACEOUS LAYER

MUD CRACKS IN LAM

TENSION CRACKS IN MUD?

VOIDS

RUBBLEISED

CHLORITE-RICH LAYERS?

MUD CLASTS

HOPPER?

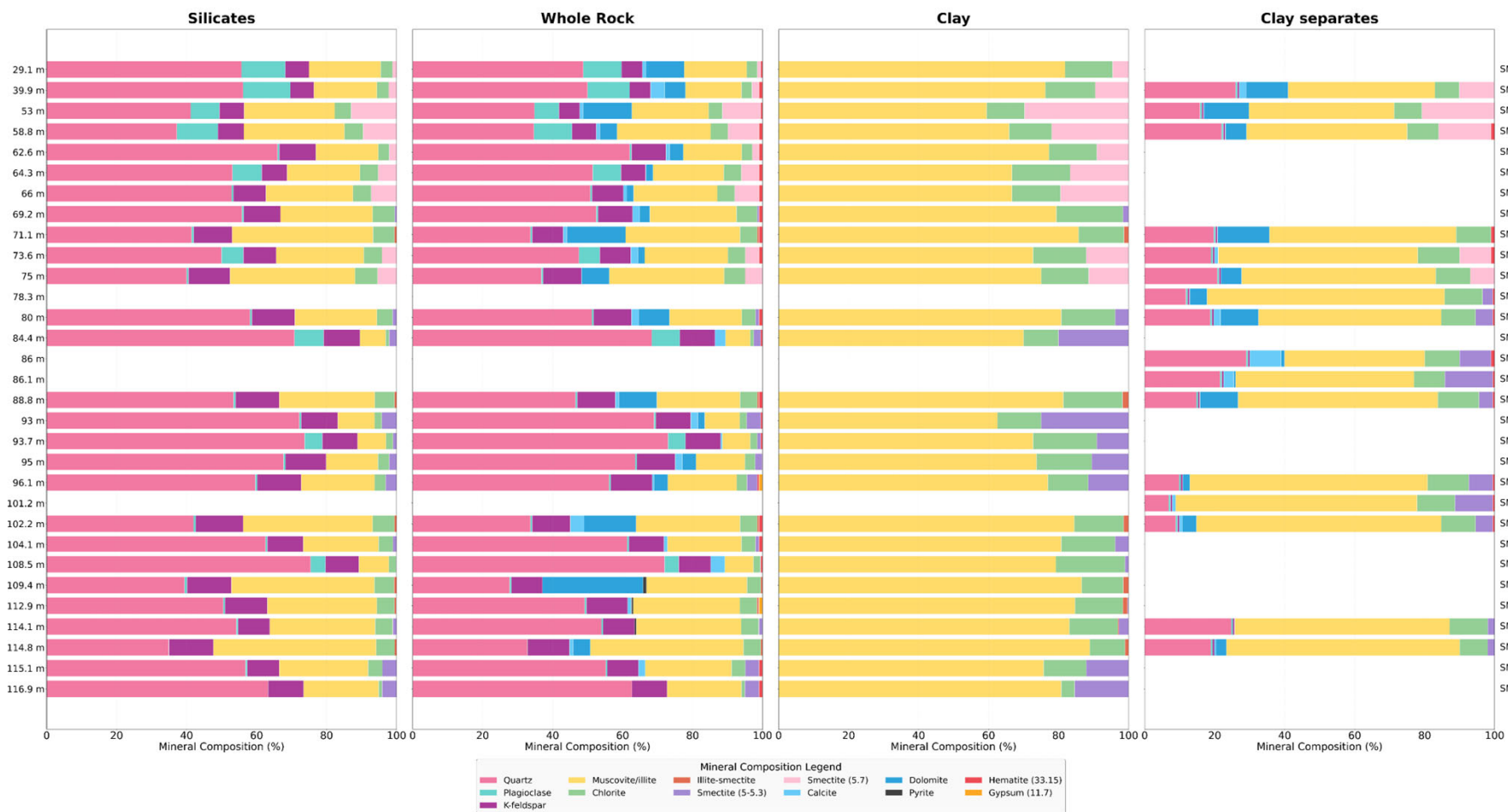
BURROW AND HOPPERS

CM-SCALE NODULE

BURROW? LENS

WEIRD MUD CLAST

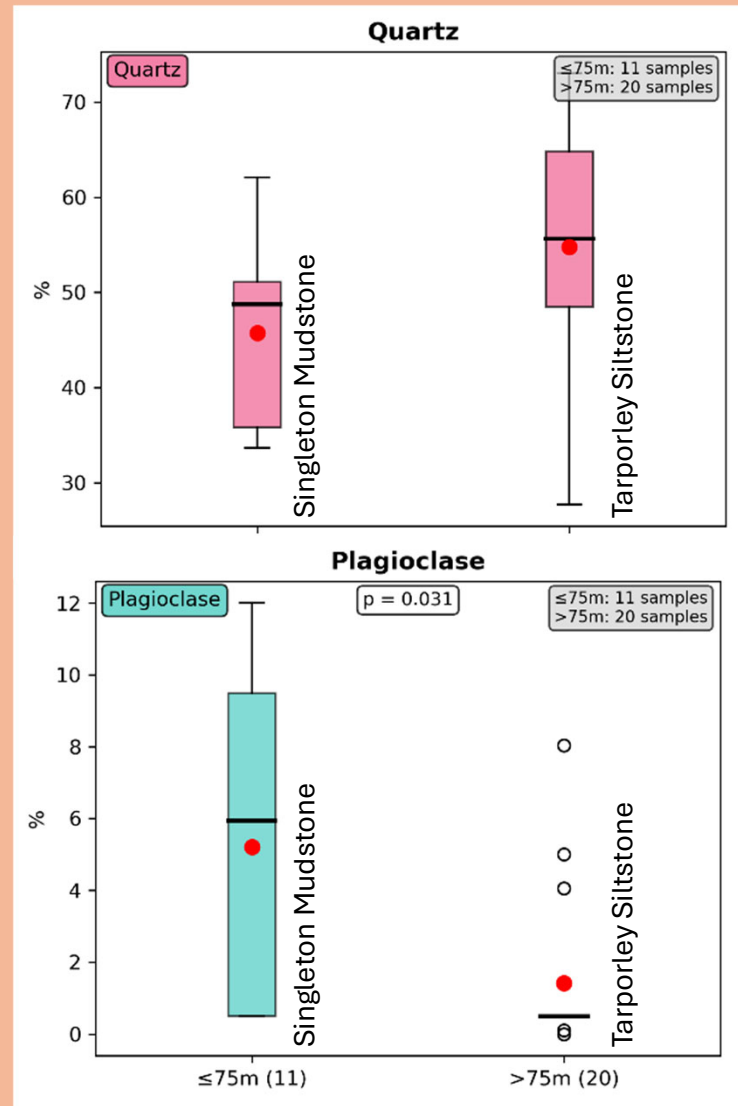
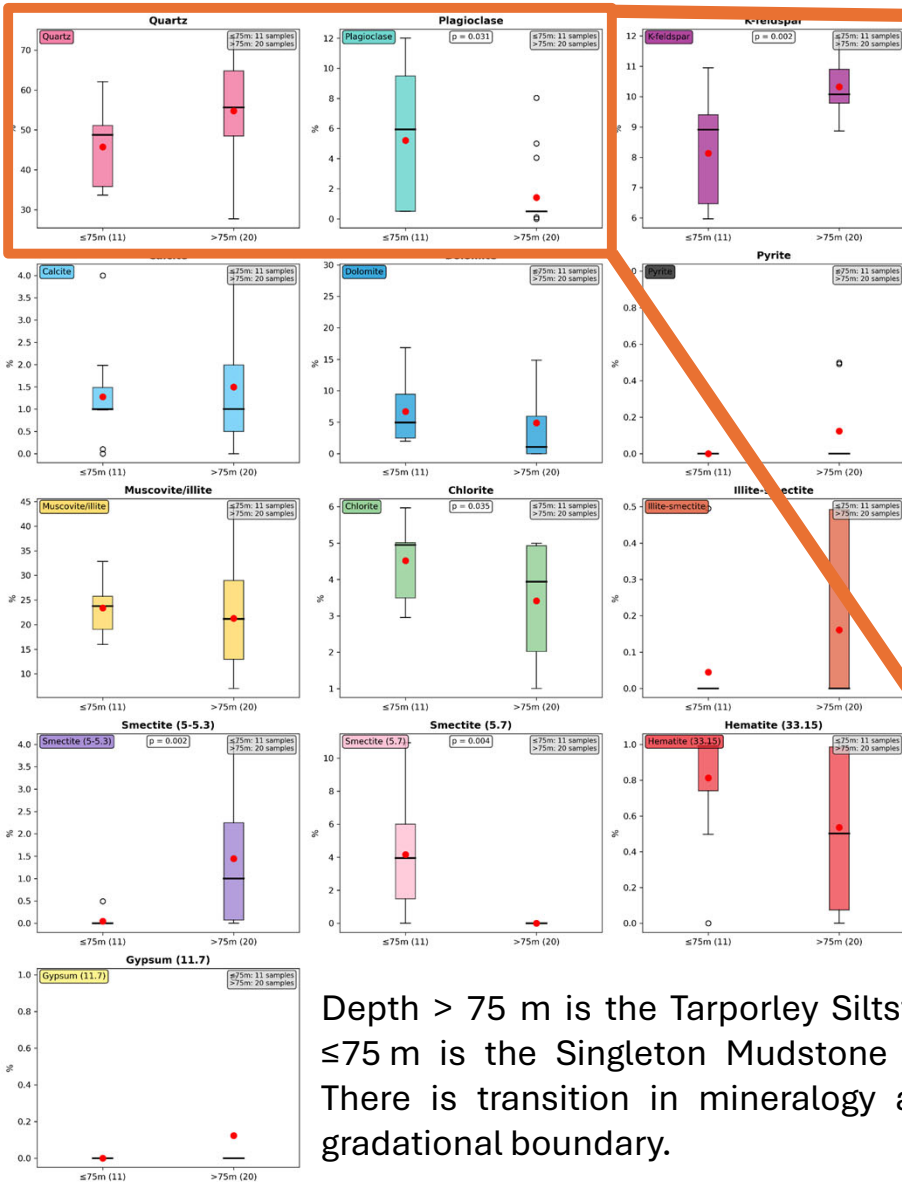
Opinions, findings and conclusions or recommendations expressed are those of the author(s) and do not necessarily reflect the views of NERC and NWS.



Mineralogy by depth

Tarporley has mean abundance of 54% quartz, 1% plagioclase
 Singleton has mean abundance of 45% quartz, 5% plagioclase

Depth > 75 m is the Tarporley Siltstone, while
 ≤75 m is the Singleton Mudstone Formation.
 There is transition in mineralogy across this
 gradational boundary.

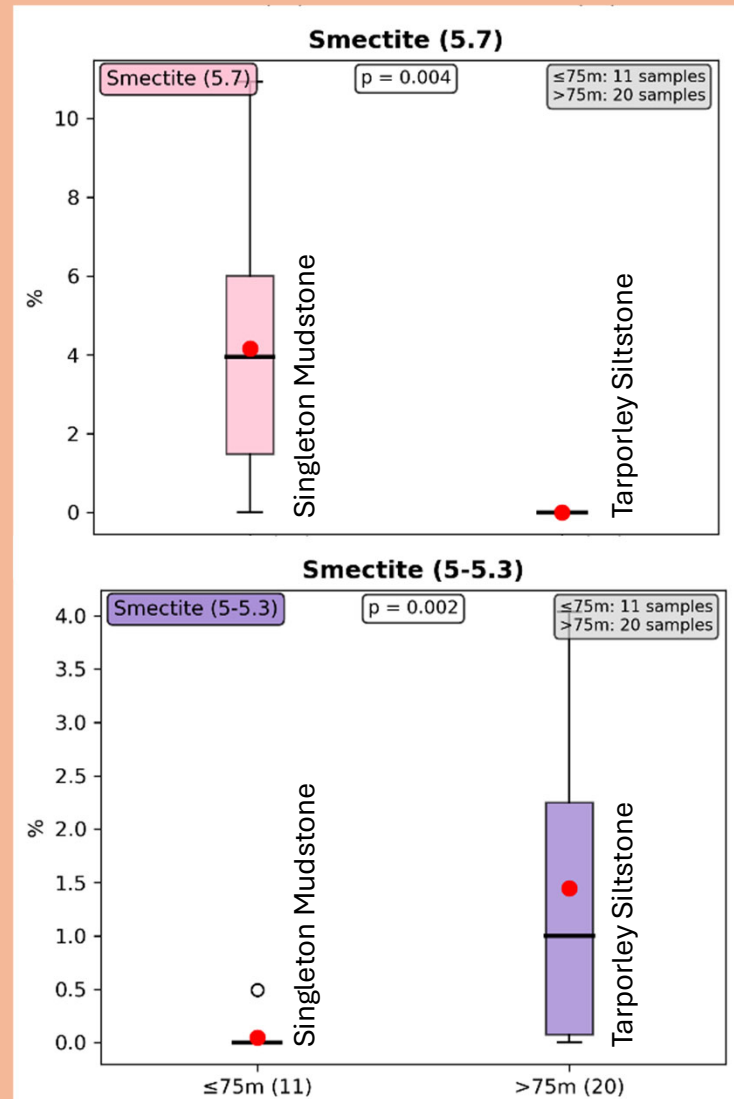


Mineralogy by depth

Tarporley has mean abundance of 1.4% smectite
Singleton has mean abundance of 4.2% smectite



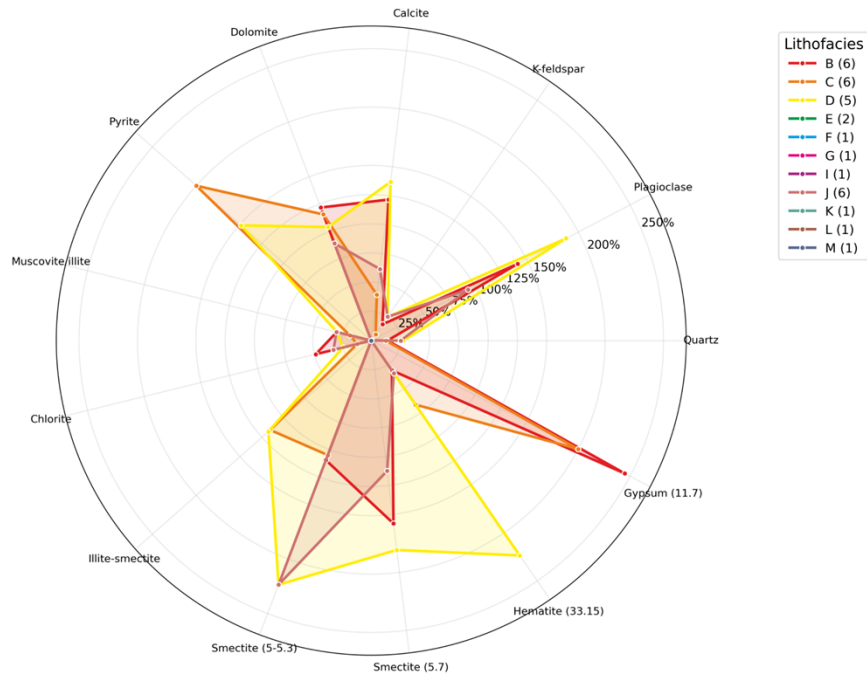
On both bulk and clay separates, a relationship where the x-ray diffraction pattern of smectite changes on the gradational boundary between Tarporley Siltstone and Sidmouth Mudstone



Mineralogical variability

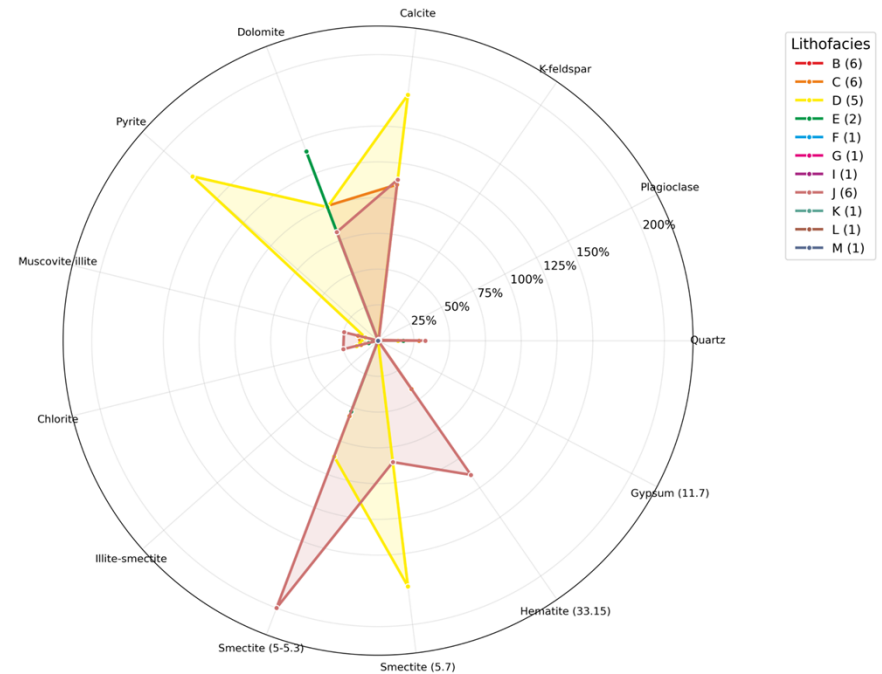
CV range	Interpretation
CV < 20%	Very consistent mineral content
20-50%	Moderate variability
50-100%	High variability
CV > 100%	Extremely high variability

**Mineral Variability Radar Chart - WholeRock
(Coefficient of Variation)**



Greatest variability in lithofacies B, C, D, and J. This correlates to the lithofacies with the most samples measured with XRD. They are also the most abundant lithofacies in the core.

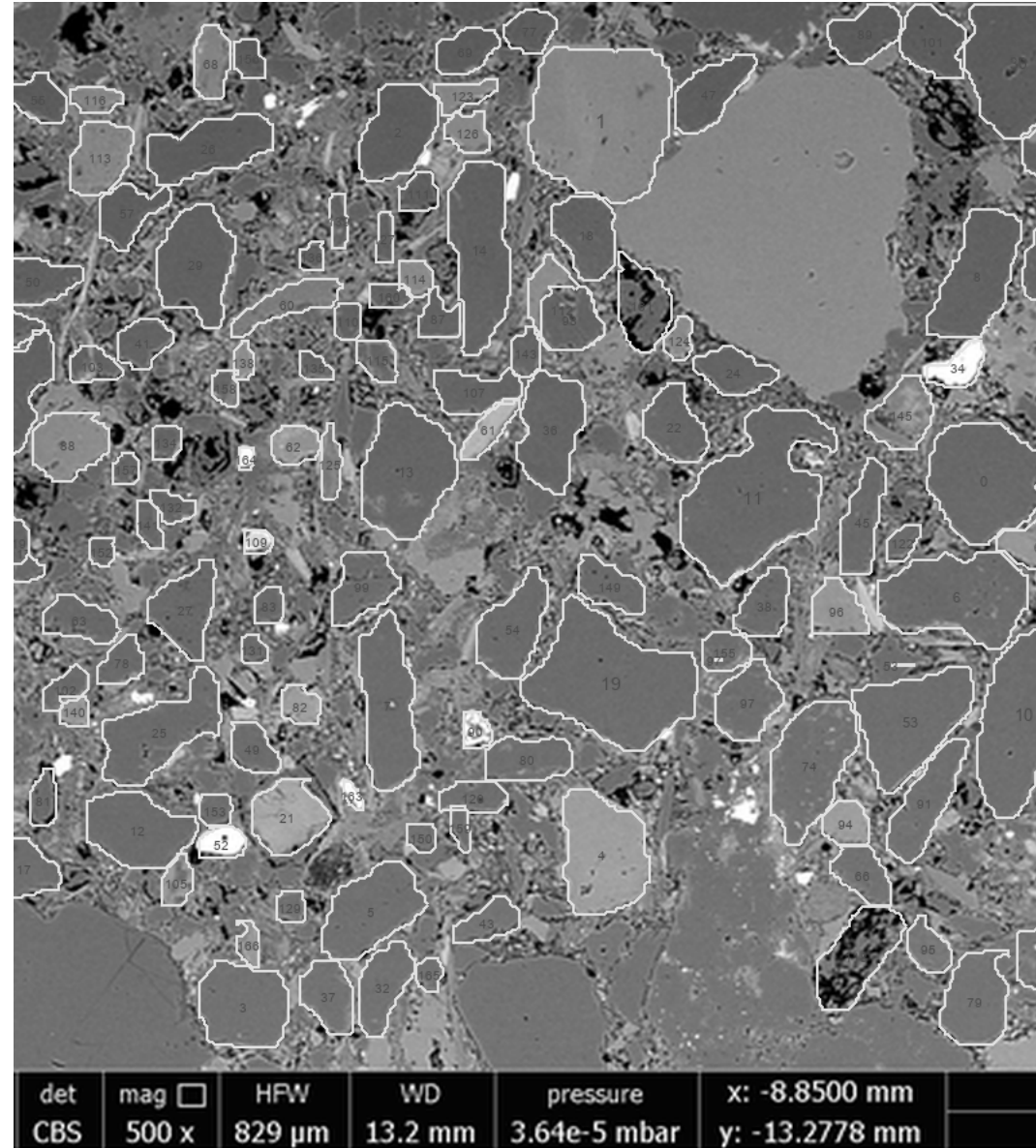
**Mineral Variability Radar Chart - OrientatedClay
(Coefficient of Variation)**



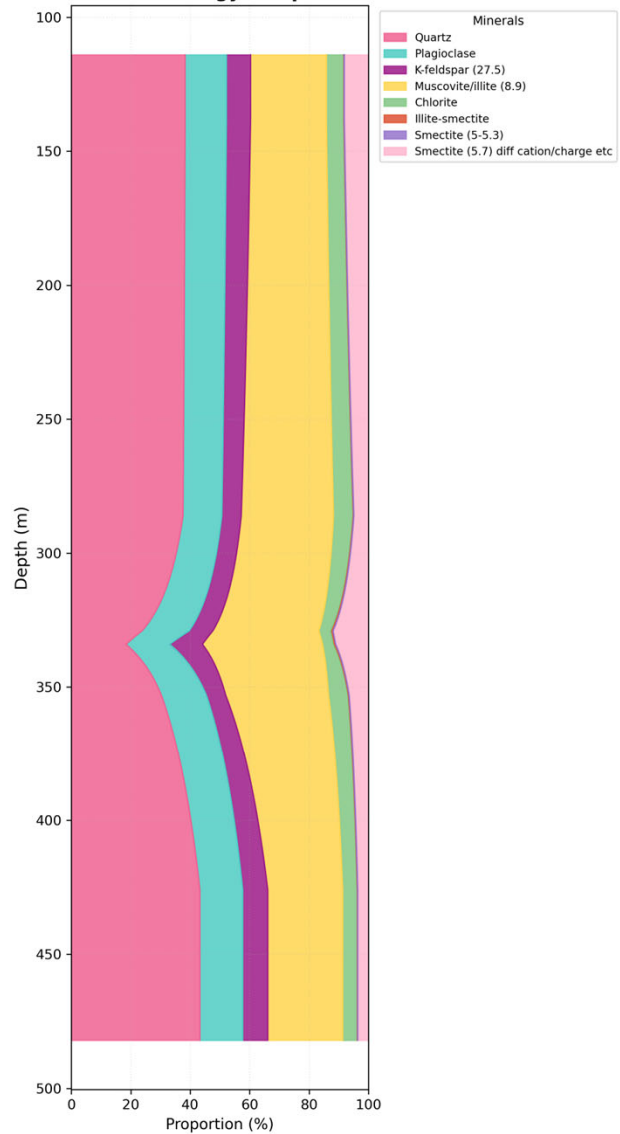
In clay separates, there is greatest variability in lithofacies C, D, and J. Again, the more abundant lithofacies. The variability is on minerals that tend to have presence or absence. The smectite types is more interesting.

GrainSight limitations

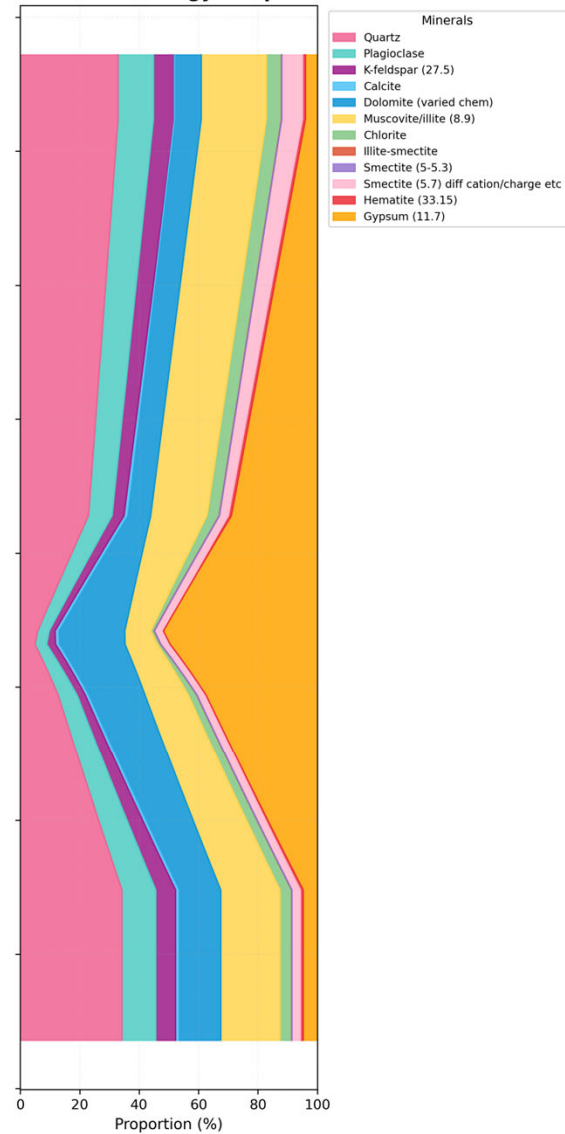
- Sometimes it is much better at identifying the larger grains, because they have better relief in the images and their borders are clearer.
- Sometimes, it preferentially identifies smaller grains and ignores the larger ones.
- Pore-filling cements are not picked out by the software.
- Biased towards larger grains, mud-sized and silt-sized are not picked out quite so well, yet silt tends to be the dominant grain size.
- Additional bias brought by initial imaging, inherent bias in where I might take images on the SEM. But I try to images across the whole cross section of the sample and move around the whole thin section to capture variability.



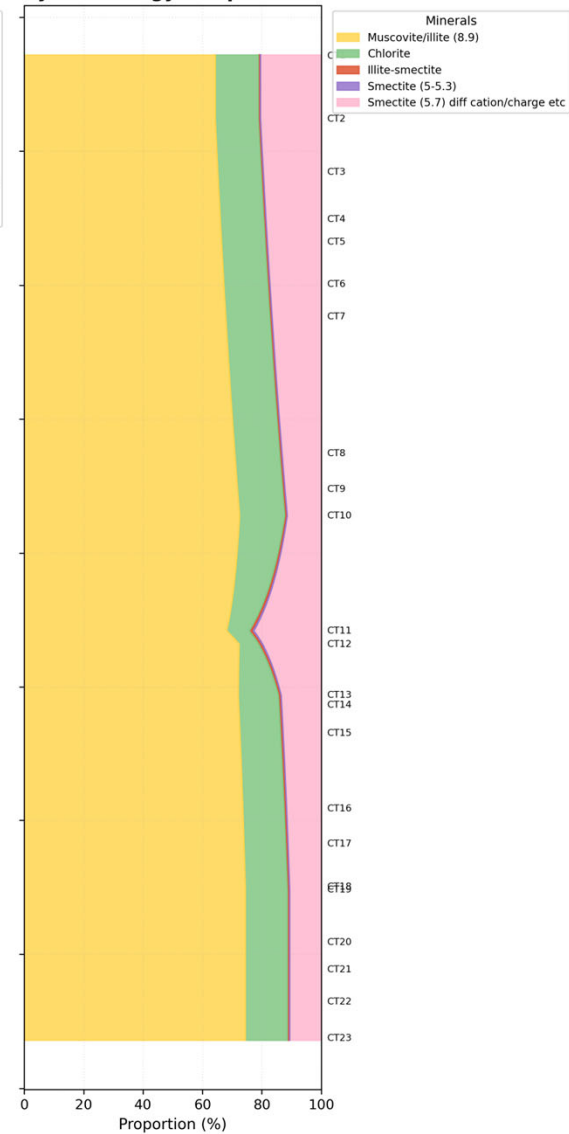
Silicate Mineralogy - Depth Profile

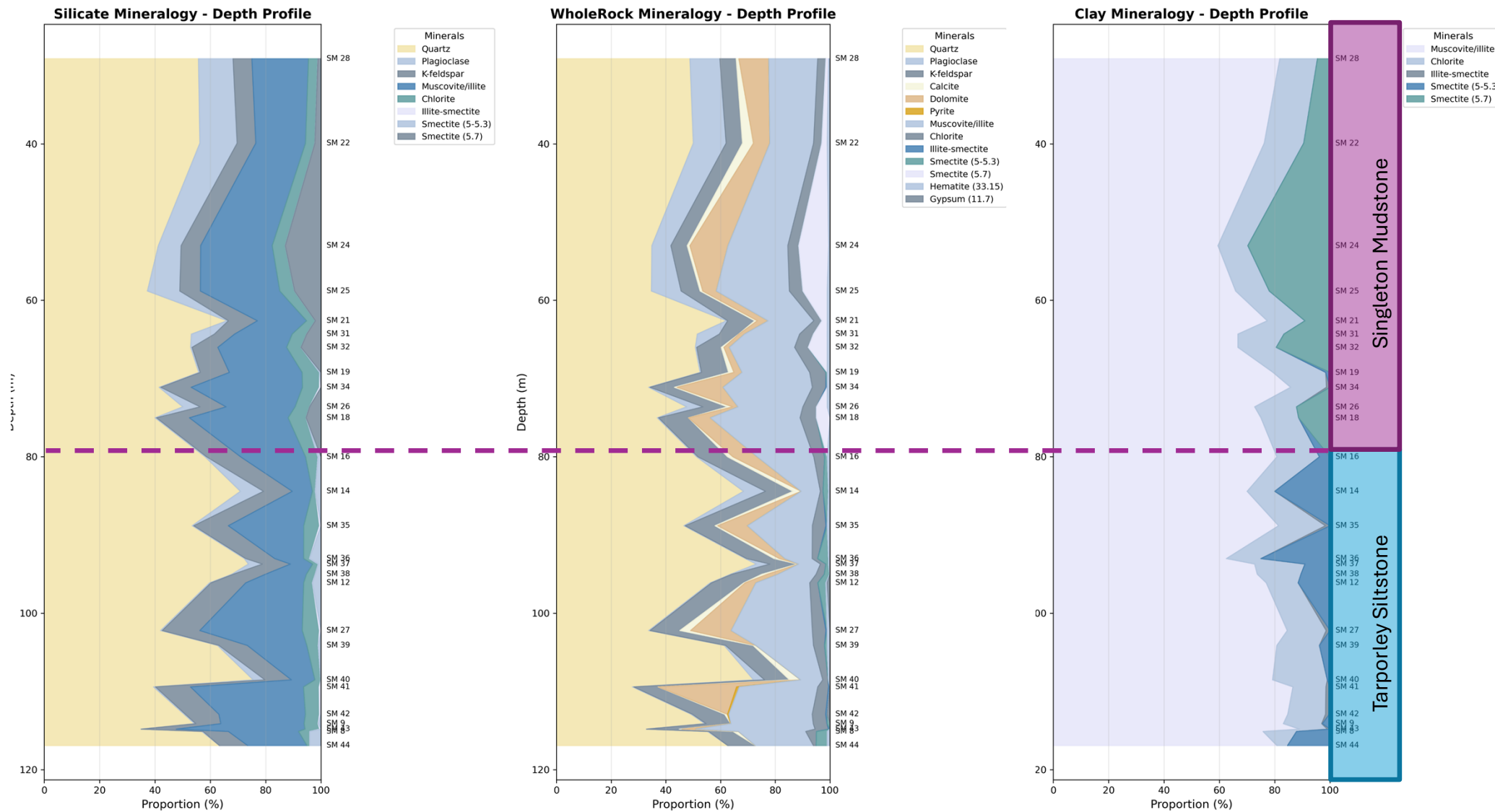


Whole-Rock Mineralogy - Depth Profile

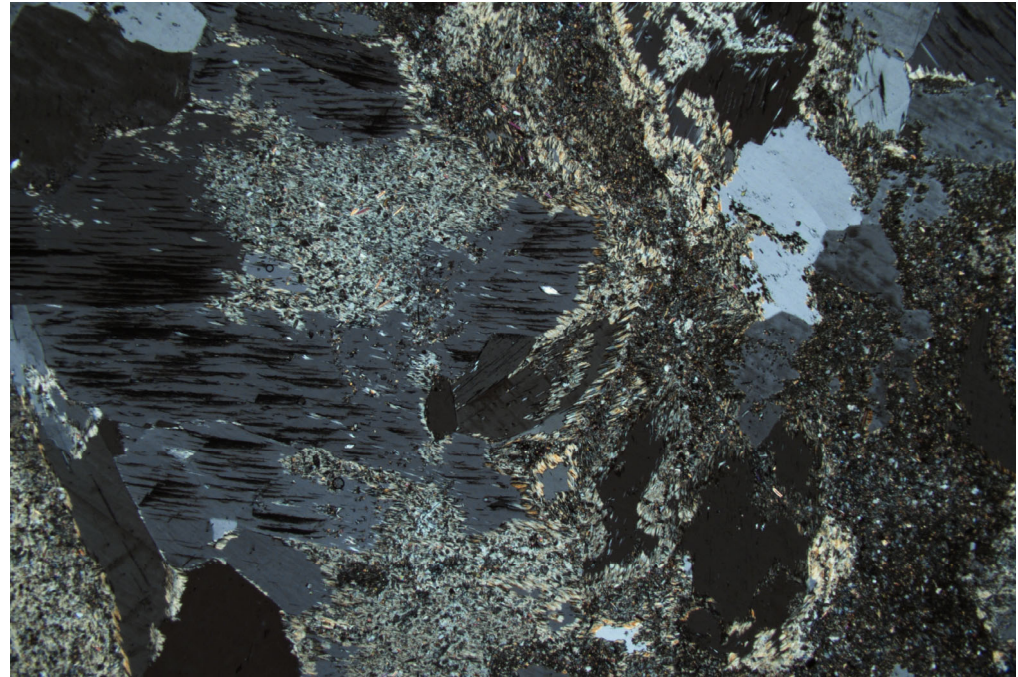
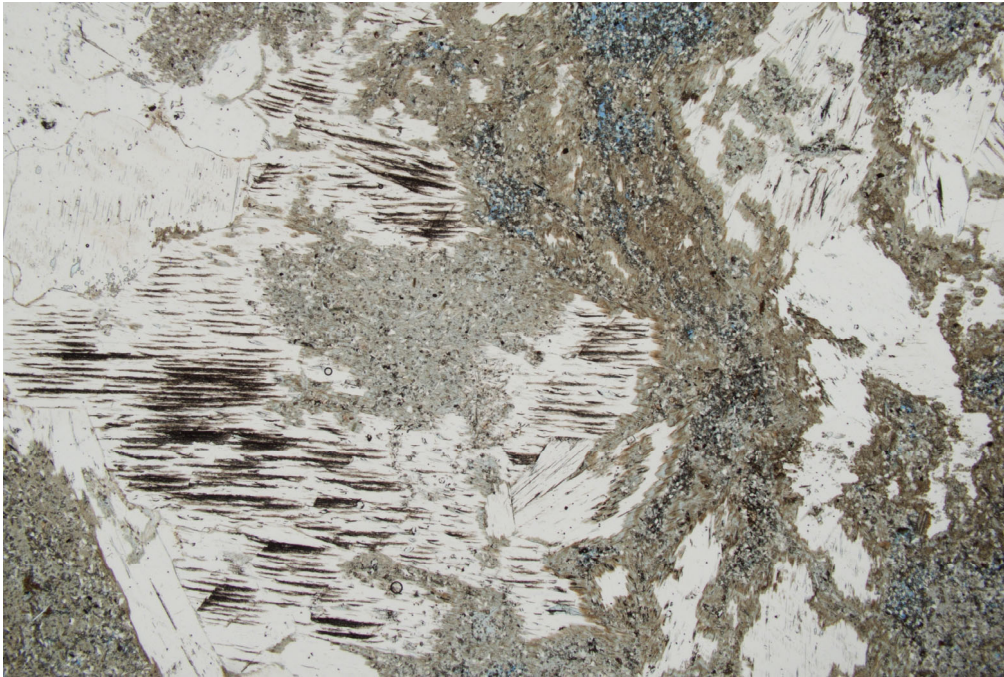


Clay Mineralogy - Depth Profile





Optical microscopy of Churchtown



Clay Mineralogy Comparison: Gateway 1E vs Saughall Massie OBH

