Burniston Mill

Further Groundwater Risk Assessment

1. Background

A further request by the Environment Agency on an assessment of risk to groundwater associated with the proposals to drill at Burniston Mill has been undertaken. It has been informed by the results of a detailed hydrogeological investigation reported in 'Hydrogeological Impact Assessment, Burniston Mill – Cloughton (PEDL 343) report reference 3729/HIA, Hafren Water Ltd, December 2024' and dialogue with the Environment Agency.

2. Methodology

The submitted HIA and this risk assessment conform to position statements included within the guidance document 'The Environment Agency's approval to groundwater protection' February 2018, Version 1.2.

This qualitative assessment has been undertaken under the general principles of a tiered risk assessment. However, the robust safeguards which are in place arising from the stringent regulatory controls are such that it is not appropriate, or possible, to undertake a generic or detailed quantitative risk assessment (GQRA and DQRA respectively).

2.1 Site characteristics

The historical and current land uses and hydrogeological setting are described in detail within the submitted HIA referenced above. The HIA document provides the requisite site characterisation information.

In terms of statutory environmental designations:

- The proposed drilling site is not within a designated Source Protection Zone
- The site is not within a Drinking Water Safeguard Zone
- The Jurassic bedrock strata are classified as a Secondary A Aquifer, which by definition 'can support local water supplies and may form an essential source of baseflow to rivers'

3. Identification of receptors

Arenaceous strata within the Middle and Lower Jurassic Strata are the key receptors with regards to groundwater risk. The Middle Jurassic Strata, which are anticipated to occur to 50.7 m below ground level, predominantly comprise yellow/brown sandstones with occasional coarser material.

Conversely, the Lower Jurassic Strata, which occur at depths of between 50.7 to 564.5 m below ground, predominantly comprise shales and sandstones, with only minor sandstones.

Based upon lithology it is anticipated that the principal groundwater resource will be within the Middle Jurassic. The entire Lower Jurassic sequence is predicted to consist of numerous aquifers of limited thickness, separated by extensive sequences of shales and siltstones, which do not represent a significant groundwater resource.

4. Source-pathway-receptor (S-P-R)

There are considered to be two potential modes of impact to groundwater; a) between the open wellbore and the surrounding aquifer during drilling and b) via the annulus, connecting a deep, saline aquifer (the Bunter Sandstone) with the Middle Jurassic aquifer.

In terms of S-P-R in the case of a) the source is drilling fluid, the pathway is the wellbore and the receptor is the Jurassic aquifers. In the case of b) the source is deep, saline groundwater and / or trace hydrocarbons, within the Bunter Sandstone, the pathway is the wellbore annulus and the receptor is groundwater within the Jurassic aquifers.

5. Mitigation of risk

5.1 S-P-R case a: Open wellbore and surrounding aquifer

During drilling, prior to the setting of steel casing, water-based drilling mud (drilling fluid) within the wellbore will be in contact with the adjacent geology.

The wellbore is anticipated to encounter groundwater once the bedrock Secondary 'A' aquifer is reached. Drilling will make use of fluid with physicochemical properties formulated to create a barrier that will prevent fluid transfer with the geological formation; the drilling fluid will rapidly create an impermeable 'mud cake' at the face of the formation. This will hydraulically isolate the formation from the interior of the wellbore, preventing the migration of fluid into the surrounding formations. Periodically during drilling steel casing will be run into the hole and cemented in place. This will act as another physical barrier (ie in addition to the mud cake) to prevent migration of fluid into the formation.

There will consequently be no significant hydraulic connection between drilling fluids within the wellbore and the adjacent formations during the drilling operation.

The well design and all details of the drilling programme, including the specification of the drilling fluid, will be submitted to the North Sea Transition Authority (NSTA) HSE and EA as part of the well program for approval.

5.2 S-P-R case b: Residual risk-migration of saline water and/ or hydrocarbon via the annulus

The proposed well construction involves the drilling and lining of the bore with successively smaller diameters of steel casing with depth.

When the target depth of each section is reached, steel casing will be installed in the bore. Cement is then pumped through the inside of the installed casing, which is consequently forced upwards through the annulus. The return of cement is recorded at surface. The integrity of the bond between the formation and casing is tested by both pressure testing and where there are concerns with respect to quality of the cement bond a (geophysical) cement bond log, known as a CBL. With these measures in place the integrity of the cement bond between the formation and steel casing throughout its entire length will be assured.

The first string of cemented casing is designed to provide an early seal for the Jurassic bedrock strata with a prognosed setting depth of around 30m below surface but this may be as deep as 50m if the Middle Jurassic Strata extends this deep.

A second string of casing is scheduled to be installed to a depth of around 192 m bgl. The depth is only indicative as while drilling the casing seat will be chosen on encountering a suitable thick and homogeneous shale/mudstone (in this case the Redcar Mudstone formation) which is approximately 141 m below the predicted boundary between the Middle and Lower Jurassic Strata.

A third 9-5/8” casing string will be run to a measured depth of around 1,404m seating in the Bunter Shale.

Finally, as the 9-5/8” casing will be cemented to surface following completion of drilling the section, the cement placed will function to isolate all formations from one-another, from the previously installed casing string and from surface.

With this placement of cement, and verification of the same, completion of this work will serve to prevent any vertical migration of fluid in the same manner as the EA proposed alternative casing design (additional casing string) with no additional risk.

Consequently, three sets of integrity tested, cemented steel casing will be present between the Middle Jurassic strata and any polluted (saline) ground water encountered at depth. **Appendix 1 & 2** further details the geological & geophysical characteristics of the Lias section, the integrity of a casing seat in this section and the potential for the presence of overpressure and/or hydrocarbon in the Sherwood (Bunter) Sandstone.

The Sherwood (Bunter) reservoir in particular is presented as posing a very low risk in terms of ground water mixing even in the extremely unlikely event of failure of the well integrity.

5.3 RISK ASSESSMENT

This assessment considers the risk associated with the migration of saline, abnormally pressured water and/ or trace hydrocarbons from the Sherwood (Bunter) Sandstone up into the Lias section and subsequent pollution of the secondary A groundwater aquifers as a result of failure of the well integrity.

Assessment Methodology

The Assessment methodology follows DEFRA's generic guidelines for the assessment and management of environmental risks. These guidelines outline a staged approach to risk assessment and are intended to guide regulatory staff in Government and its agencies, as well as those carrying out assessments, to reach a decision on managing environmental risk.

A hydrogeological risk assessment at the proposed Cloughton appraisal well has been carried out using the Source-Pathway-Receptor (S-P-R) methodology described in the Environment Agency's H1 Environmental Risk Assessment framework – Annex J (Groundwater). Where S-P-R linkages have been identified, the sensitivity of the receptor, magnitude of impact and significance of effect has been considered in order to assess potential risks.

Receptor Sensitivity

The sensitivity of water resource receptors is based on their status and considered resource value.

Magnitude of Impact

The magnitude of a potential impact on a receptor depends on the nature and extent of the proposed development and is independent of the sensitivity of the water resource.

Significance of Effect

The significance of the potential effect is derived by combining the assessments of both the sensitivity of the water resource and the magnitude of the impact in a simple matrix, as presented in the Table below. Effects which are assessed to be major or moderate are considered to be significant, whilst those that are minor or negligible are not significant.

Receptor Sensitivity	Magnitude of Impact			
	High	Medium	Low	Very Low
Very High	Major	Major/Moderate	Moderate	Moderate/ Minor
High	Major/Moderate	Moderate	Moderate/ Minor	Minor
Medium	Moderate	Moderate/ Minor	Minor	Negligible
Low	Moderate/ Minor	Minor	Negligible	Negligible

Source-Pathway-Receptor Linkage (migration of polluted groundwater from Sherwood Sandstone into Lias and then into primary and secondary aquifers)

As discussed above the embedded mitigation renders the risk as negligible as the well is designed, modified, commissioned, constructed, equipped, operated, maintained, suspended and abandoned such that there is no unplanned escape of fluids from the well and that the risks to the health and safety of persons or the environment from it or anything in it, or in strata to which it is connected, are as low as is reasonably practicable. (Ref. The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996).

The table below summarises the S-P-R risk analysis

Source Of Impact	Pathway	Receptor	S-P-R Linkage	Likelihood of occurance	Receptor Sensitivity	Magnitude of Impact	Significance of effect without mitigation	Embedded Mitigation	Significance of effect with embedded mitigation	Additional mitigation	Significance of effect with additional mitigation
Overpressured Saline groundwater in the Sherwood Sandstone	Failure of well casing and cement	Groudwater bearing formations above the Redcar Mudstones in the Lias which may have direct linkage to secondary A aquifers	Yes	Extremely Low	Very High	Medium	Major / Moderate	Secure and tested casing seats in the Redcar Mudstone and Bunter Shale and integral casing and cement seal achieved	Negligible	CBL and /or remedial cement operations	Negligible
Mobile hydrocarbon in the Sherwood Sandstone	Failure of well casing and cement	Groudwater bearing formations above the Redcar Mudstones in the Lias which may have direct linkage to secondary A aquifers	Yes	Very Low	Very High	High	Major	Secure and tested casing seats in the Redcar Mudstone and Bunter Shale and integral casing and cement seal achieved	Negligible	CBL and /or remedial cement operations	Negligible

6. Summary

A qualitative groundwater risk assessment has been undertaken using the source-pathway-receptor approach. The previously submitted HIA provided the details of the geology and conceptual hydrogeological model.

Two potential pathways have been identified. However, the proposed methods of drilling and well construction are such that the identified risks are considered to be mitigated, resulting in there being no significant risk to groundwater, either during drilling or residual risk upon completion or abandonment.

The well design and drilling procedures will conform to best practice and are approved by the regulators North Sea Transition Authority (NSTA), HSE and the EA as part of the well permitting and program approval process.

Appendix 1: Discussion on the Lias & Sherwood (Bunter) Sandstone

Geological & Geophysical note to address concerns with respect to a casing seat in the Lias section and the potential for overpressure and/or hydrocarbon in the Sherwood (Bunter) Sandstone.

Discussion on the 13 3/8" Lias Casing Point within the Cloughton-2 well

In the Cloughton 2 well the planned 17 ½" hole will be drilled into the Liassic section. Historically this has been the location for setting a variety of casing sizes. Within the wells surrounding the Cloughton-1 well every well to date has set casing within the Liassic section. In some wells the casing is set immediately after passing into the Liassic and passing out of the Middle Jurassic section and its associated aquifers of the Dogger and Ravenscar groups. In other wells a section of Liassic is drilled before the casing point is reached.

In order to confirm the presence of a regionally coherent and sealing casing seat in the Lias section a detailed examination has been carried out to identify the best seat within the area for the proposed 13 3/8" casing which is planned for the Cloughton-2 well. It should be noted that an actual casing position within the Liassic section is not fixed.

The Liassic section is composed of a number of different formations that are informally named after their type localities. The Liassic section is well exposed in coastal outcrops in the Cleveland area. The Liassic is also drilled by many wells within the local area. The Liassic section as a whole is well exposed in the UK in a swathe from Cleveland to the Wessex Basin and can be seen both at outcrop and within individual wells. Within the Cleveland basin the Main units within the local area from top to bottom are the Blea Wyke sandstone formation, the Whitby Mudstone Group, the Main Seam (ironstone), the Cleveland Ironstone Group, the Staithes Sandstone group and the Redcar Mudstone group. This section represents sedimentation from the Toarcian to Pleinsbachian ages. These rocks reach up to 450m thick and are renowned for their rich fossil content (ammonites) and their excellent exposures. A virtually complete succession of shallow-marine exposure is evidenced. Within this section there are two first order shallowing upward trends from deeper marine mudstone deposited below storm wave base through quartz siltstones and sandstones or shelly mudstones deposited above storm wave base in the shoreface domain, to Fe rich deposits at the top of the succession. A stratigraphic comparison of the Cleveland basin together with other UK basin is shown below. A simplified sketch of the formations seen at outcrop near Boulby are also shown below.

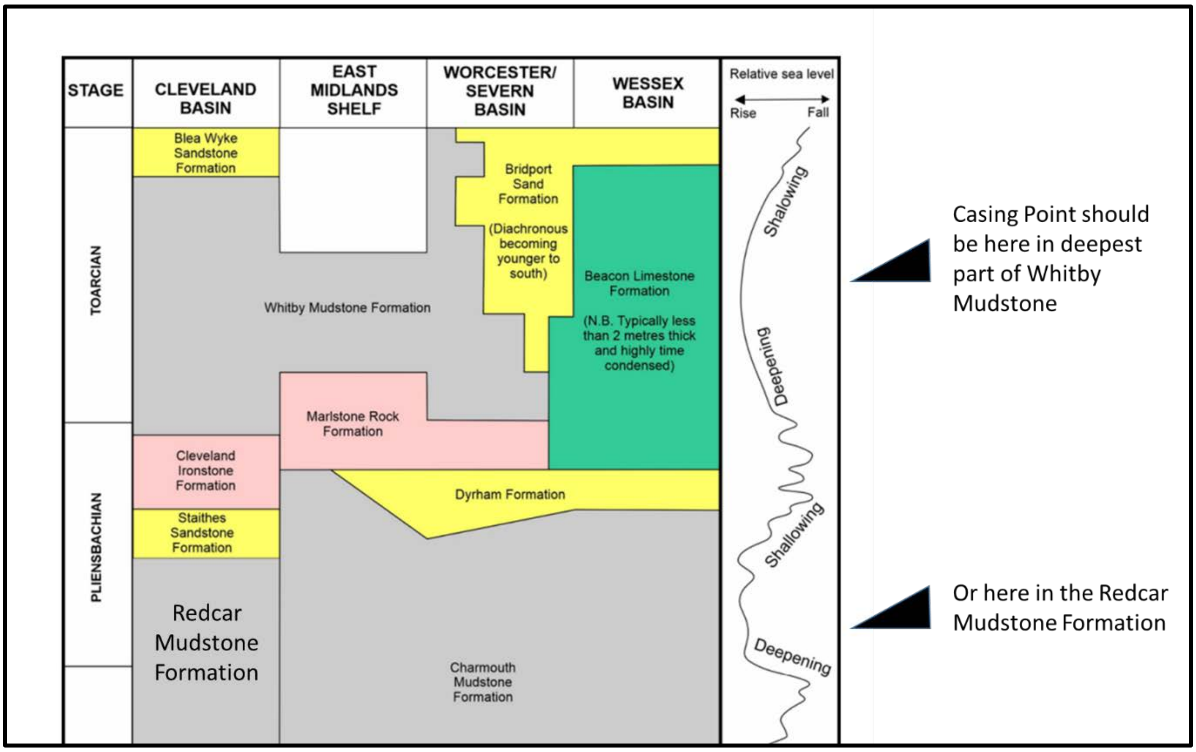


Fig. 2 Stratigraphy of the Cleveland Basin compared to other Liassic basins in the UK. Note the two shallowing upwards cycles on the right. Suggested casing points in the deeper marine facies are shown on the right hand side.

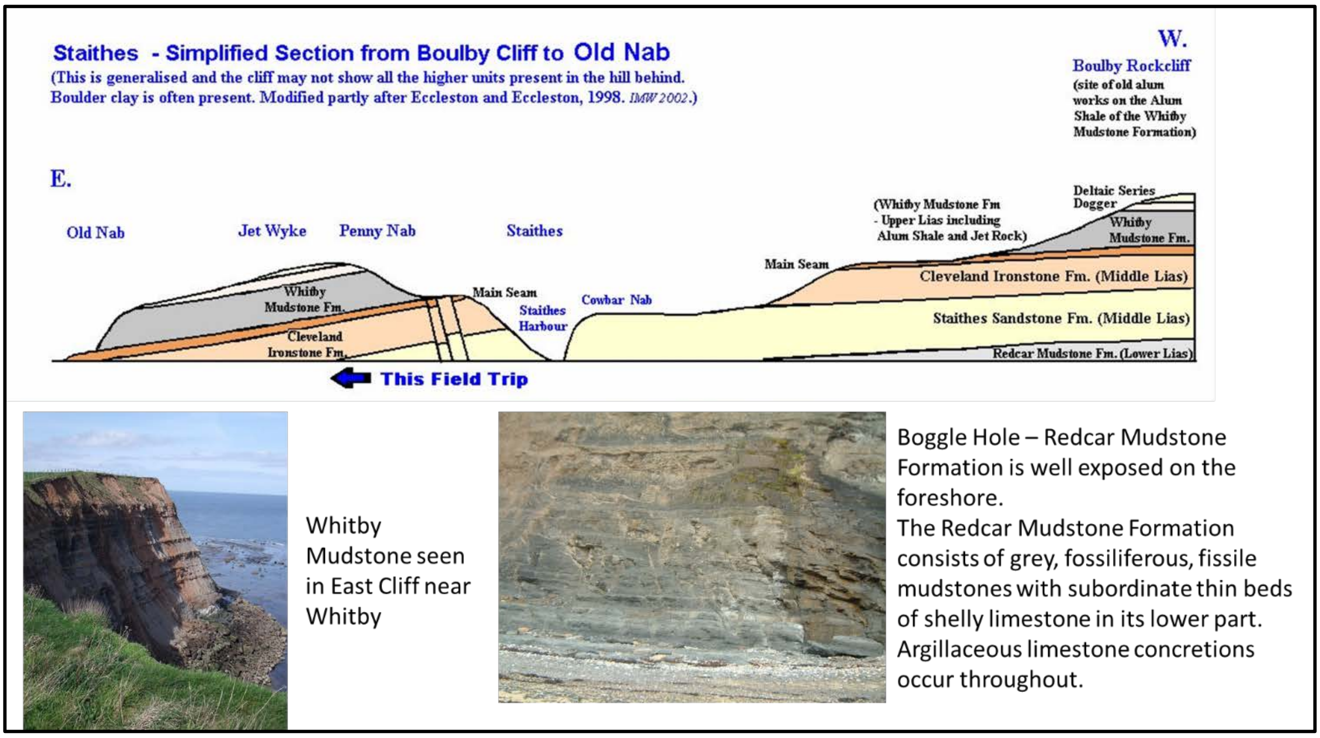


Fig. 3 Simplified section from Boulby Cliff to Old Nab after Eccleston. Note the position of the Whitby Mudstone section below the Middle Jurassic and the Redcar Mudstone section. Photos from outcrops of both are seen at the base of the figure.

The BGS has done extensive work tying the onshore wells with the Cleveland outcrop. The full Liassic section has been drilled by multiple wells within the Cloughton-2 regional area. At outcrop the Whitby Mudstone group represents a coarsening upwards succession passing from deeper marine and anoxic and organic shales with multiple ammonites zones passing upwards into a locally preserved Blea Wyke Sandstone Formation. The section is composed of dark brown shales and organic rich darker shales. This would make an ideal candidate for the casing seat within the Lias. The lithology is shale prone and the section thickness in local wells (Lockton and Cloughton) is over 75m thick. It is readily identified by its high GR (even through casing) and shale returns on the cuttings. The Cleveland Ironstone formation and the Staithes Sandstone represent a condensed section and are composed or shales, siltstones, ironstones and occasional sandstones. The section is again highly fossiliferous. This section would not make the best casing seat and should be avoided. The section is readily identified on the wireline logs as having relatively lower GR readings and having a more saw toothed profile on the GR log. Although predominantly shaley in nature the higher volume of siltstone and occasional sandstone make this a poorer casing seat then the mudstone above.

These units mark the top of a shallowing upwards succession. Below these units lies the deeper marine Redcar Mudstone Group. This consists of marine shales with occasional anoxic conditions developed. The formation consists of alternating shales and organic rich mudstones and is dark grey to black. In places source rocks are developed with higher GR zones shown on GR profiles. These shales can occasionally be iron rich with frequent pyrite. These shales would make ideal targets for a lower casing point within the Lias. The section is around 75m in thickness and almost all shale prone. A good LOT would be expected within this section.

Below this section the lower part of the Redcar Mudstone Group consists of the Siliceous shales and the underlying Calcareous shales. These represent a shallowing upwards sequence with the calcareous shales predominantly indicating deeper water facies with increased carbonate sedimentation. The Siliceous shales as the name suggest are more quartz rich and grade to siltstone and minor sand facies, as such these sediments are not expected to make ideal seats for the casing shoe.

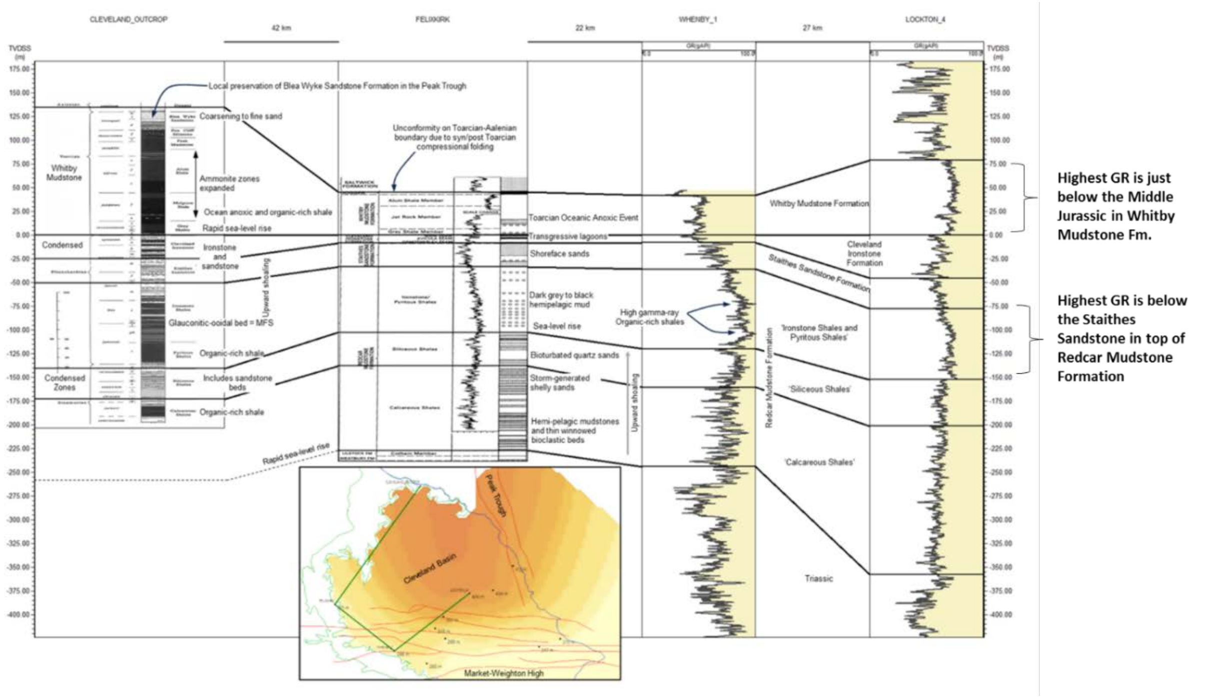


Fig. 4 The diagram above taken from the BGS shows the comparison of the outcrop data within the local area compared with the drilled data from the Lockton well (very close to Cloughton). The best zones from a casing seat perspective are highlighted.

The Cloughton-1 well has drilled the full section of Liassic stratigraphy. The upper section was logged through casing but the higher GR events of the Whitby Mudstone and the Redcar Mudstone are still obviously seen. The well has its 18 5/8" casing set within the Siliceous shales section. The Cloughton well Liassic stratigraphy can be seen below:

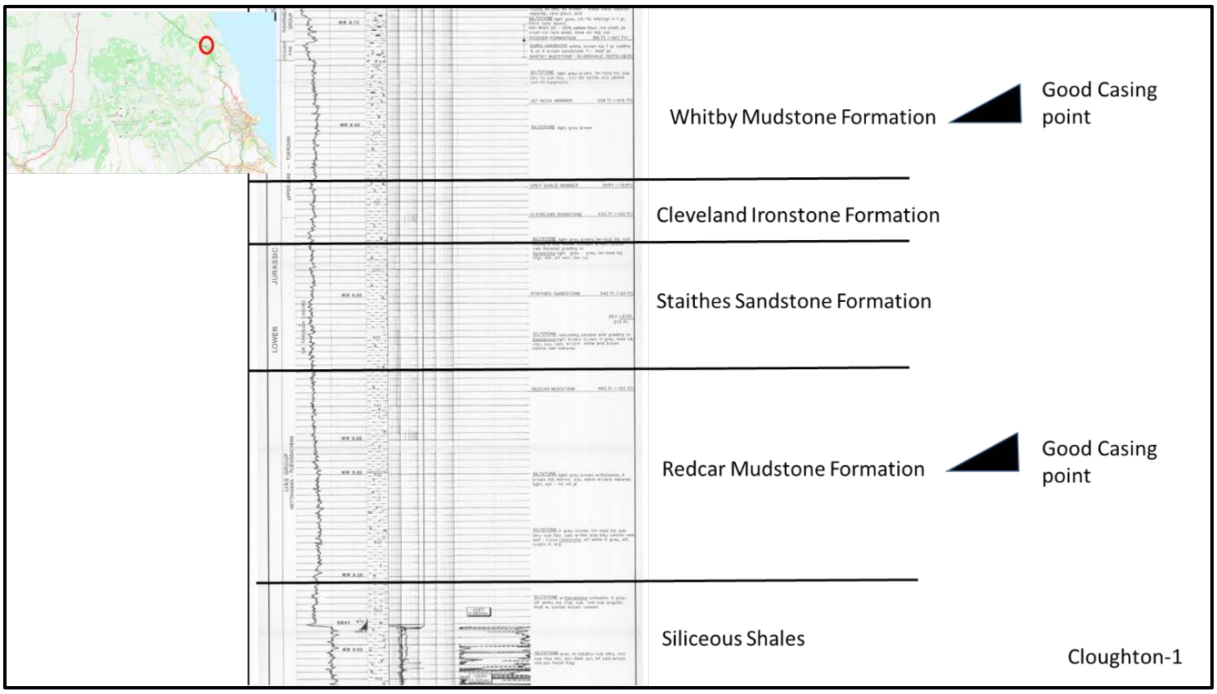


Fig. 5 Cloughton-1 well Liassic Stratigraphy

The Cloughton-1 well 18 5/8” casing was set within the Siliceous shales but a very good leak off test (LOT) was still achieved of 15.6 ppg EMW which demonstrates that even this section can provide a suitable casing seat.

The closest offset well to Cloughton is the Lockton East well. This well lies approximately 9km to the SW of Cloughton-1 and approximately 8km to the WSW of the proposed Cloughton-2 well. The Liassic stratigraphy can be seen below.

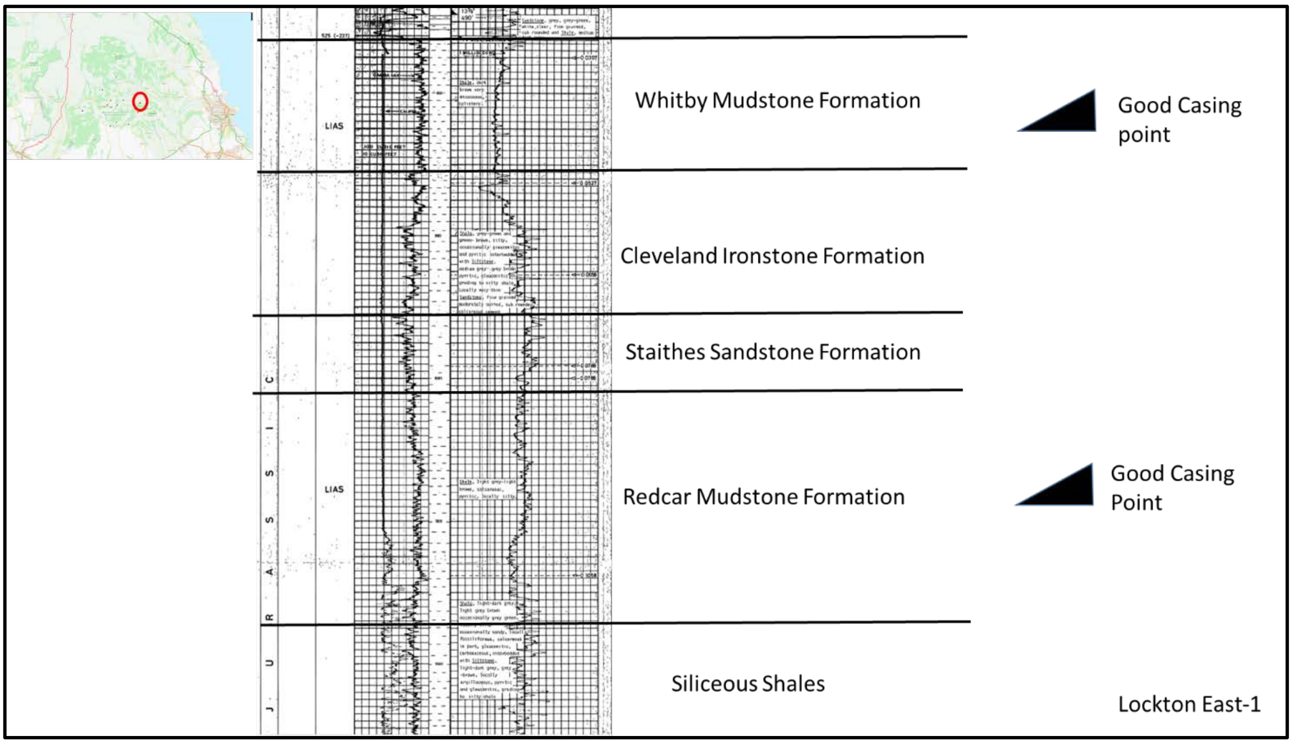


Fig. 6 Liassic Section within the Lockton East well.

Again a full succession of Liassic section was drilled by the well. The GR in this well is not logged through casing. The Whitby Mudstone section and the Redcar Mudstone sections clearly stand out as the highest GR sections and identification of the main units is relatively straightforward. It should be noted in this well that the 13 3/8” casing was set at the base of the Middle Jurassic. There was a marked high GR shale (logged afterwards) towards the base of the Middle Jurassic and it would appear that the casing point was picked on cuttings from this marker. However this section was a high GR shale within the Middle Jurassic. The Whitby Mudstone Group is over 200ft thick. The well was drilled in 1981 however before the use of LWD.

Modern drilling BHA’s with GR close to bit together with the need to see at least 50ft of cuttings would make this casing point pick very straightforward. The lower mudstone the Redcar Mudstone Formation is clearly seen on the GR and described as shale, light grey-light brown. This would make another good casing point within the Lias.

The Ebberston Moor-2 well was another regional well that drilled a total thickness of Liassic section. In this well the complete section of Liassic units was drilled with the Whitby Mudstone Formation, Cleveland Ironstone Formation, Staithes Sandstone Formation, Redcar Mudstone Formation and the Siliceous Shales. The Whitby Mudstone and Redcar Mudstone look like good seats within the well and in this well the casing was set within the Whitby Mudstone Formation. Both formations were shale prone with the Whitby Mudstone described as medium to light grey, firm, tabular, non-calcareous, slightly gritty, slightly waxy to greasy lustre, generally homogeneous, trace to locally dark carbonaceous debris, rarer local pyrite. The Redcar Mudstone is described as medium to dark grey, slightly to moderately hard, tabular, non-calcareous, highly gritty texture, dull lustre, slightly carbonaceous. Within this well the upper shale – the Whitby Mudstone was used as the casing seat for the 18 5/8” section. The Ebberston Moor -2 well Liassic Section can be seen below.

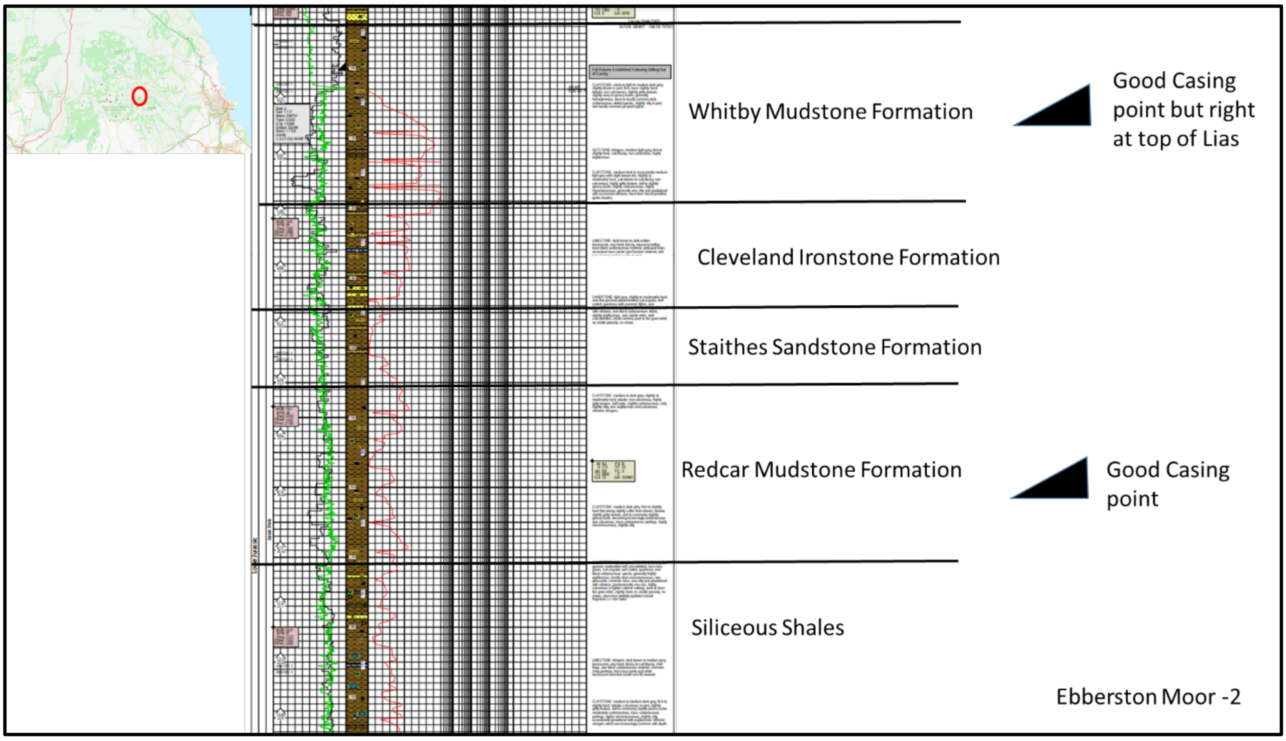


Fig. 7 Liassic Section within the Ebberston Moor 2 well.

Conclusion

The Liassic section within the Cleveland basin is well known and extensively studied due to classic type locality outcrops and multiple well penetrations of the complete section. Overall the Liassic is a shale dominated succession reflecting an overall shallow marine section. However variations in sea level over this period can alternate conditions from deeper marine with occasional source rock deposition to shallow marine/stormface with wave evidence and tidal influence recognised on the sediments. The shalier sections are represented by marine flooding events that shallow upwards. Within the Liassic exposure both the Whitby Mudstone formation and the Redcar Mudstone formation reflect deeper marine conditions and shale dominated deposits – evidenced at outcrop and on GR profiles and cuttings returns. The Siliceous shales, Staithes Sandstone Formation and Cleveland Ironstone Formation represent shallow water conditions and more siliceous content representing proximity to material being fed from the Lower Jurassic mainland. As they are still shale dominated they would most likely still make an acceptable casing seat as demonstrated by the Cloughton 1 well.

The deepwater deposits of the Whitby and Redcar Mudstone Formation are considered the best casing points in the Liassic section.

The regional areal depth and lateral continuity of these two formations as a basis for providing a seal to water movement is presented as part of a geophysical interpretation of the Lower Jurassic sections (see **Appendix 2: Cloughton Shallow Mapping**).

Both the Whitby and Redcar Mudstone Formation formations are guaranteed to present an integral seal for any cemented casing relative to any ground water aquifers. In particular the Redcar Formation is prognosed to be encountered at a depth of 199m (653 ft) below the surface at the Cloughton appraisal well location.

Discussion on the hydrocarbon bearing potential of the Sherwood (Bunter) Sandstone

Within Germany and parts of Holland the Sherwood Sandstone can make a valid hydrocarbon exploration target. The sandstone has reservoir porosity and permeability and would flow at producible rates. There is a good regional top seal in the form of the Rot Halite which is a halite top seal providing an excellent seal to the system. There are often valid anticlinal traps formed by movement within the mobile salt layers of the underlying Zechstein. The trap, seal, reservoir and timing within the system can be present however overall success rates in Germany are low. The major failure mechanism is lack of charge. The source rock within the Bunter sandstone play is the Carboniferous coals and Namurian shales. These are some distance below the Bunter sandstone and the overlying Zechstein is thick, plastic and extensive. The Zechstein makes a world class seal rock with thick extensive evaporites. Hydrocarbons within the Zechstein are possible where the Z1 (Kirkham Abbey) overlies the gas bearing Carboniferous. Charging the Brotherton limestone is difficult but not impossible, and relies on faulting coming up from the Carboniferous into the Zechstein.

However at the Bunter level the underlying Zechstein prevents hydrocarbon migration into the overlying Triassic section. Faults within the Mesozoic section sole out on the Zechstein salts in the top of the Zechstein. Faults within the Carboniferous die out on the entering the Zechstein. As such there is no direct pathway from the Carboniferous into the Triassic.

This is evidenced by the Sherwood Sandstone being water wet in the regional area – although most of the parameters for a hydrocarbon play are present the thickness and composition of the Zechstein makes migrating hydrocarbons into the Triassic very difficult which is why the Sherwood is not seen as a play within the local area. Regional experience from the East Irish Sea also shows that the Rot Salt top seal is not effective over a prolonged period of time (due to its low thickness).

The Sherwood Sandstone is also known as the Bunter sandstone (Bunt means coloured in German) and is found in a large swathe of the UK but predominantly in a strip from the Cleveland Basin to the Wessex Basin in the south. It is a reservoir in the Wessex Basin evidenced by the Wytch Farm oil field and also forms the reservoir for large fields in the East Irish Sea, Northern North Sea and in offshore Ireland. The sand outcrops in north east England and is drilled extensively in many parts of the Cleveland Basin.

The unit comprises predominantly sandstones and pebbly sandstones with lesser amounts of conglomerate and minor amounts of mudstone and siltstone. It was deposited in the late Permian to Triassic period. Generally the sandstone is clean and well sorted and makes an excellent reservoir in areas where the sandstone has not been deeply buried (or buried and exhumed). The sandstone is susceptible to grain on grain compaction, dissolution and cementation. The environment of deposition is predominantly fluvial sandstone in a braided river succession with minor amounts of aeolian sandstone and subordinate shale and evaporitic material. The sandstone is reddish brown in most localities and varicoloured.

In the Cloughton-1 well a thick and clean succession of Sherwood Sandstone was drilled. The overall thickness of the unit was 313m and the unit comprises >90% sandstone with subordinate siltstone and claystones. The sandstone is described as clear, translucent, light brown, orange, friable to medium hard, fine to medium grained, rounded to sub rounded with calcitic cement. Poor to fair intergranular porosity with no shows and abundant loose, frosted medium to coarse grained quartz. No gas readings were noted in the sandstones and there was a clear flat resistivity curve throughout the reservoir indicating the formation was water bearing, no shows were encountered. The reservoir becomes a little shalier towards the bottom with more frequent intercalations of shale. The section passes conformably into the Eskdale Group Saliferous Marls which comprise coastal and evaporitic sections of sands, shales and siltstone with frequent halite cements. Underlying this succession is evaporitic successions of the Zechstein group.

The sandstone was of moderate quality however and it was water bearing at this locality. The upper 200ft of the Sherwood Sandstone can be seen below. This represents typical facies experienced in the Cloughton well and regionally.

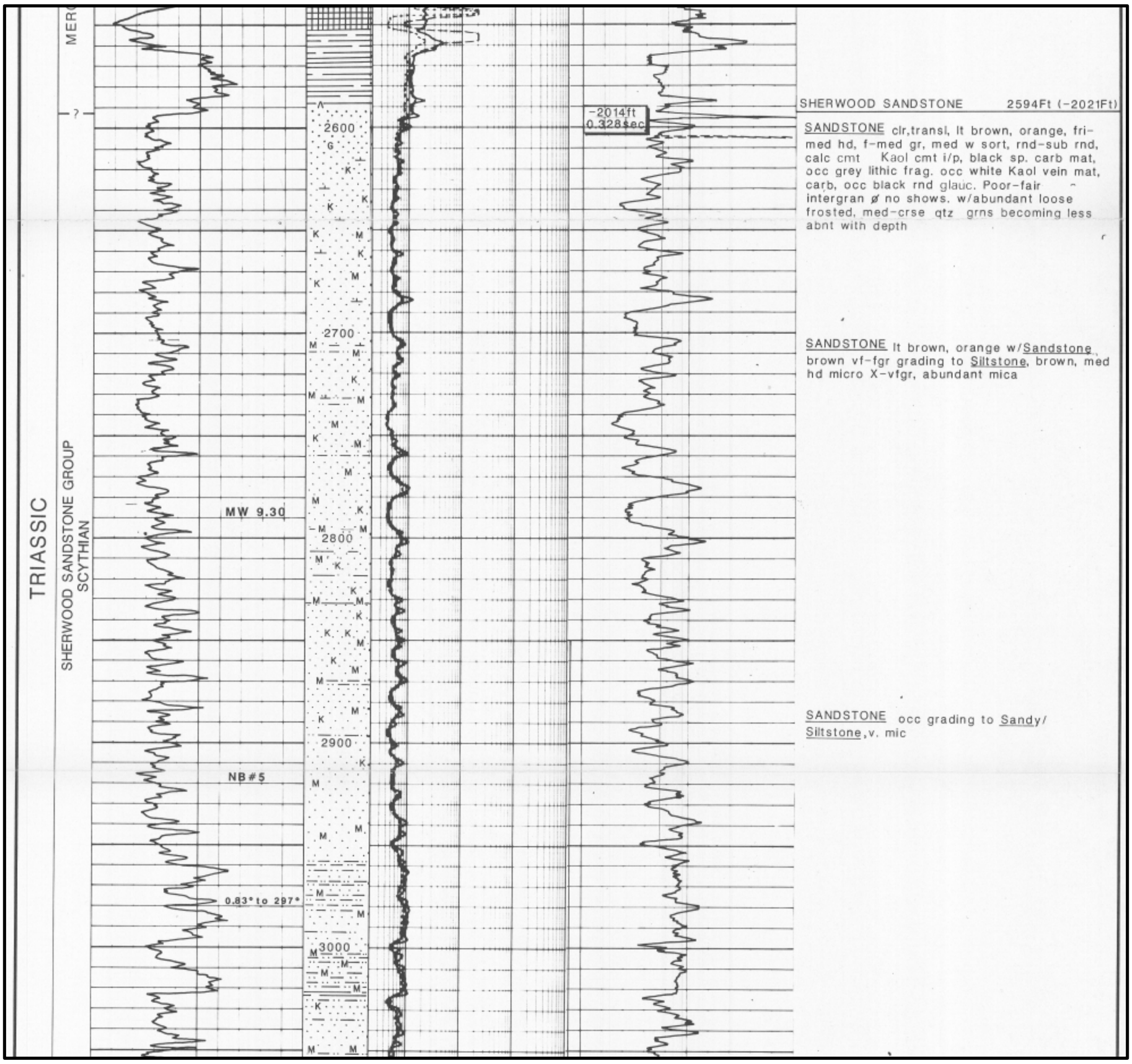


Fig. 8 Cloughton-1 well Sherwood Sandstone Section

Hydrocarbon potential of the Sherwood Sandstone within the area of the Cloughton structure

Europa has examined the hydrocarbon potential in the Cloughton area with respect to the Cloughton well and the planned well. There is a closure (structure) at Base Permian level and within the Carboniferous at the Cloughton well but no closure at the Top Sherwood level. Cloughton-1 sits on a plunging Sherwood high that continues to rise to the north, outside of the Cloughton area. Regional 2D section suggest the Top Sherwood continues to rise until the Robin Hood Bay area. As such no hydrocarbons are expected in the Cloughton-2 area due to lack of charge and lack of trap, the Cloughton-1 well confirmed this - no hydrocarbons were found.

The structural map of the Sherwood Sandstone in the greater Cloughton area can be seen below. NB the map is in feet. As can be seen from the map the Cloughton areas sits on a regional nose with spill up dip from the Cloughton planned well (shown with an S).

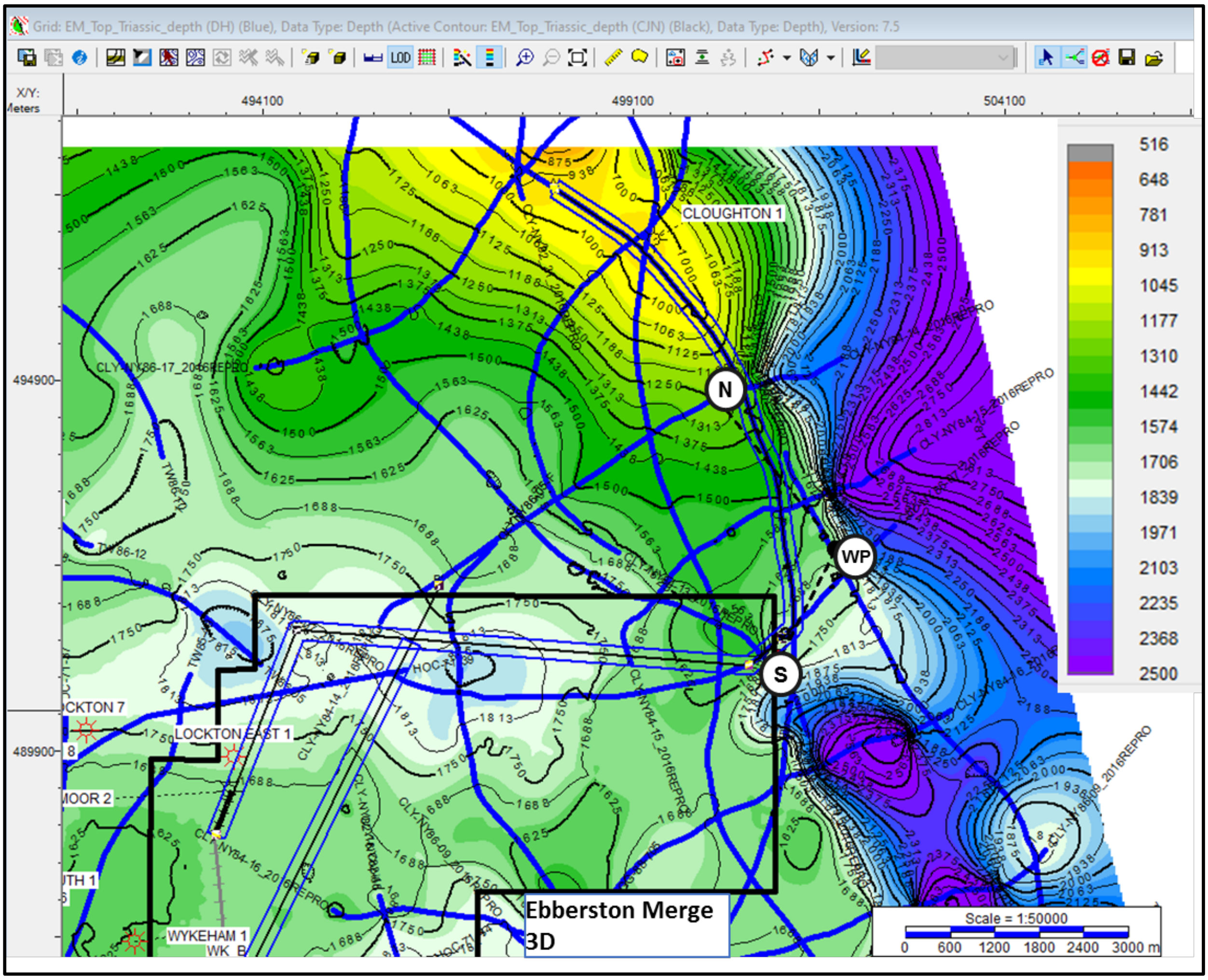


Fig. 11 Top Sherwood Sandstone Map for the Greater Cloughton Area (in feet)

A regional seismic line from south to north can be seen below. It goes through the Cloughton well and the proposed location of the Cloughton-2 appraisal well (marked by S). As the seismic data shows the Sherwood Sandstone rises up to the Robins Hood Bay anticline where there is the possibility of a trap. However the Stoupe Beck-1 well has drilled the anticline very close to the position of the Robin's Hood Bay -1 well. The Stoupe Bay well found thick and porous Sherwood sandstone but the formation was water bearing with no shows encountered. Even on a regional high with a charge migration focus the well was wet.

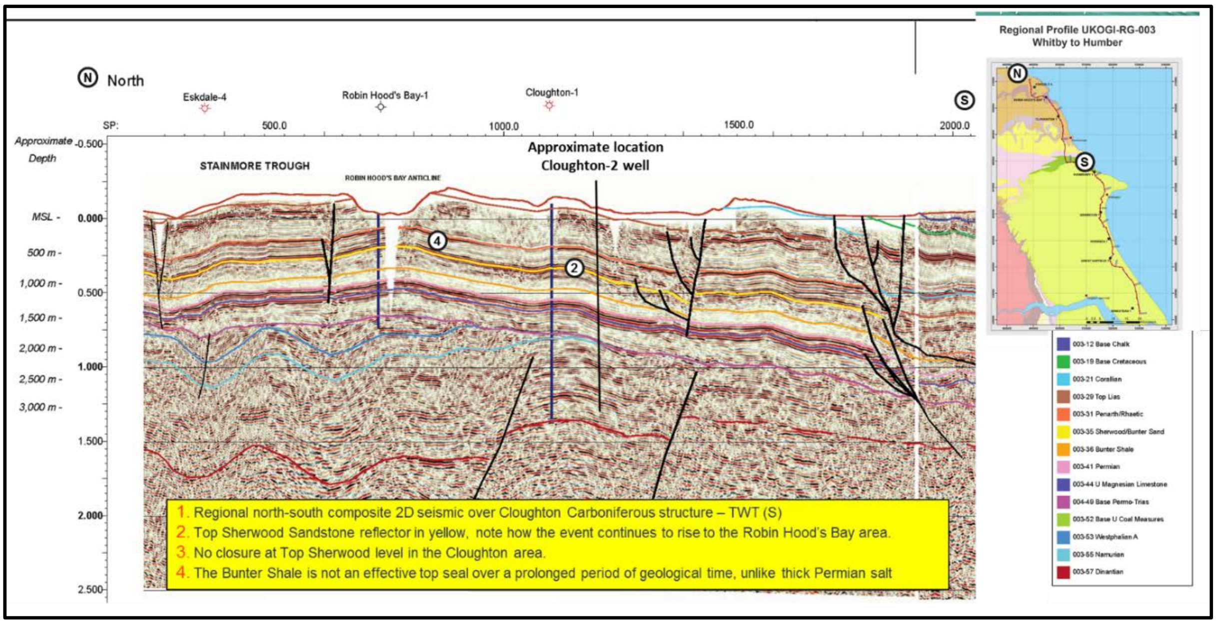


Fig. 12 Regional 2D seismic line through the Cloughton area and the Robin Hood's Bay anticline.

Salinity and pressure within the Sherwood Sandstone

In the vicinity of the Cloughton well and the proposed appraisal well the Sherwood Sandstone will be charged with highly saline, non potable water. This is the case in almost all the Sherwood Sandstone aquifers with the exception of where the Sherwood is close to surface where some fresh water aquifer recharge is occurring over 40 km to the west of Cloughton.

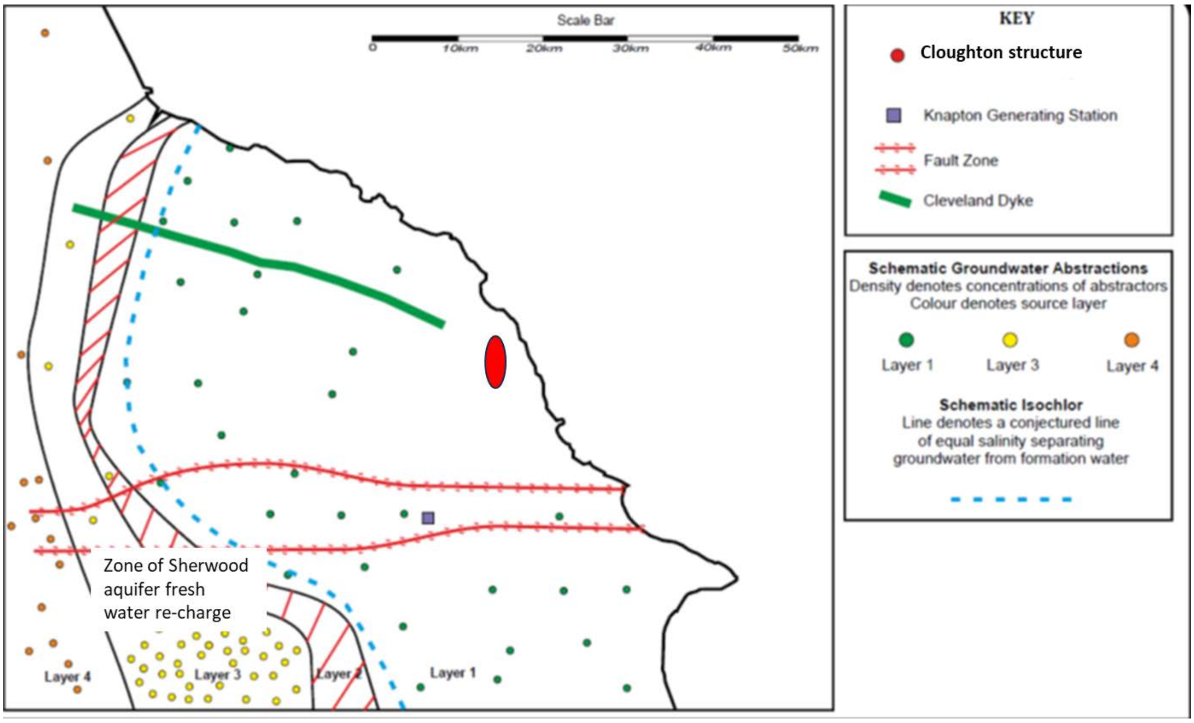


Fig. 13 Layer 1 upper & middle Jurassic aquifers, Layer 2 impermeable lower Jurassic & Mercia, Layer 3 Zone of Sherwood Sandstone freshwater recharge, Layer 4 Permian

The Sherwood is saline for a number of reasons. Primarily the sandstone lies directly above the Zechstein and Saliferous Marls sections. Within both these formation large amounts of halite are present. Dissolution of these halites by groundwater flow has created a saline groundwater which passes into the directly overlying Sherwood Sandstone. The Sherwood Sandstone especially towards the base of the succession has naturally occurring halite cements which dissolve within the formation water creating saline formation waters. Lastly overlying the Sherwood Sandstone is the Rot Halite. This prevents the movement of fluids out of the Sherwood Sandstone. It is also a 100ft thick halite which further adds to the salinity within the system. The Sherwood is under and overlain by halite as such the system is essentially sealed with halite end members, the fact that the Sherwood aquifer is saline should be expected.

No evidence has been found to support any over pressure in the region with regards to the Sherwood Sandstone. The expectation would be to encounter a normally pressured saline aquifer in hydrostatic equilibrium.

In conclusion the Sherwood sandstone is prognosed to be a normally pressured, highly saline reservoir in the Cloughton area and more particularly in the Cloughton 2 well. The Sherwood reservoir in terms of over pressured saline water or hydrocarbon in the area of the Cloughton gas field is extremely unlikely to be a risk in terms of ground water mixing.

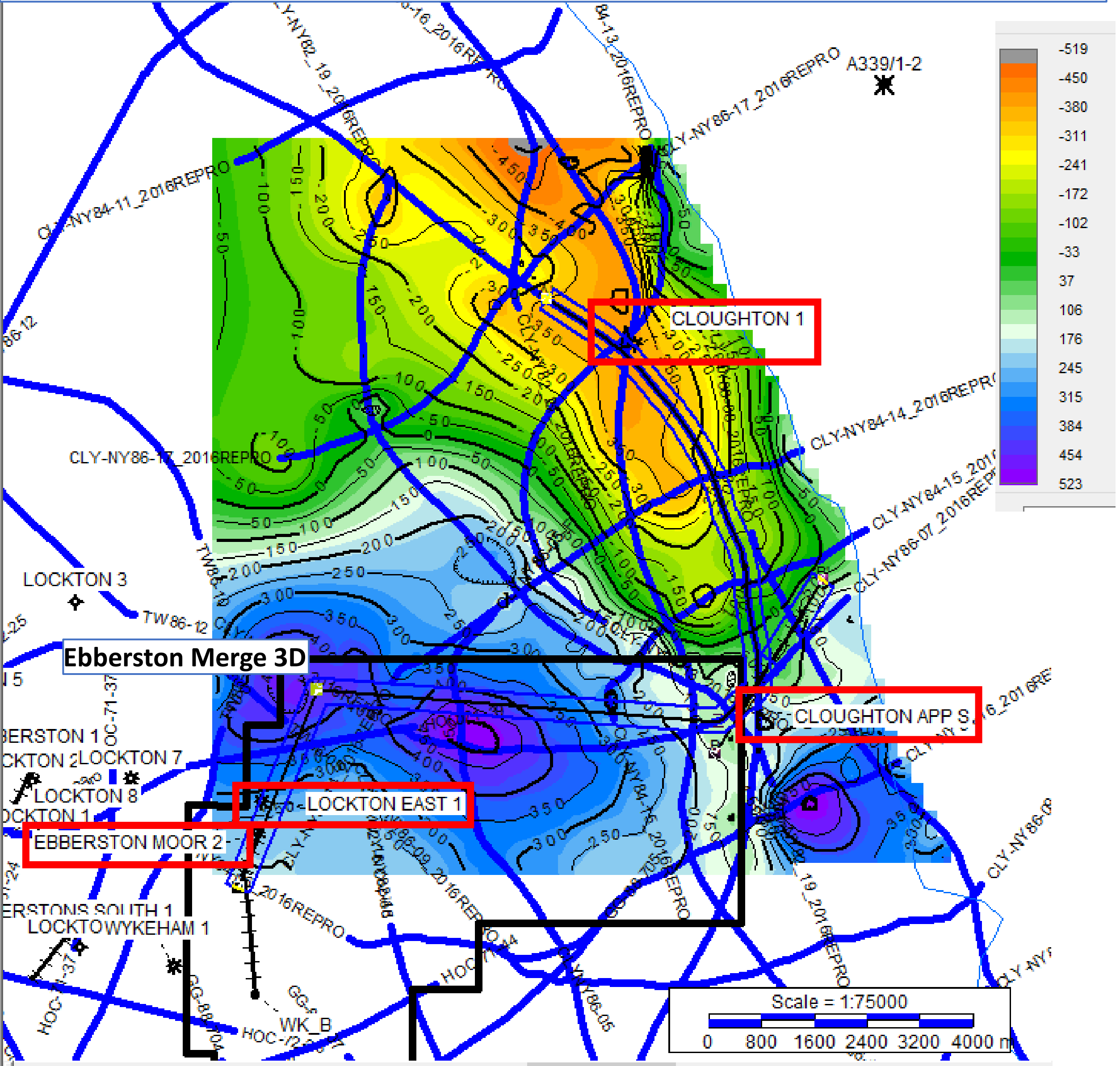
Appendix 2: Cloughton Shallow Mapping

PEDL 343 Cloughton
Shallow Mapping

July 2025

Cloughton Shallow Mapping - Summary

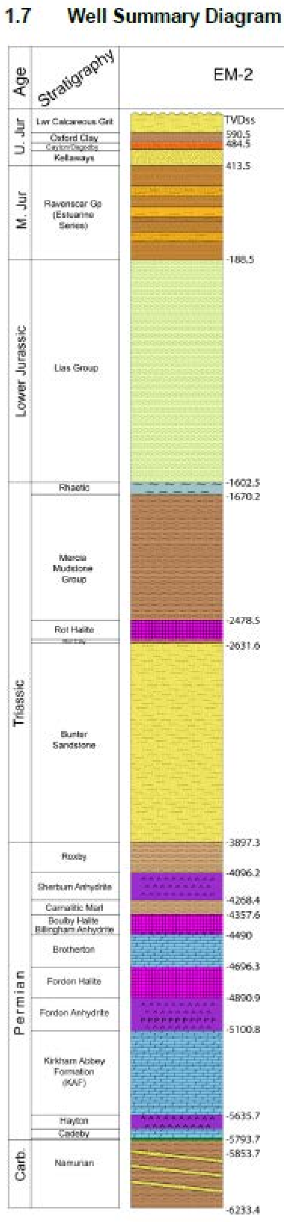
Top Whitby Mudstone Depth Feet (Europa July 2025)

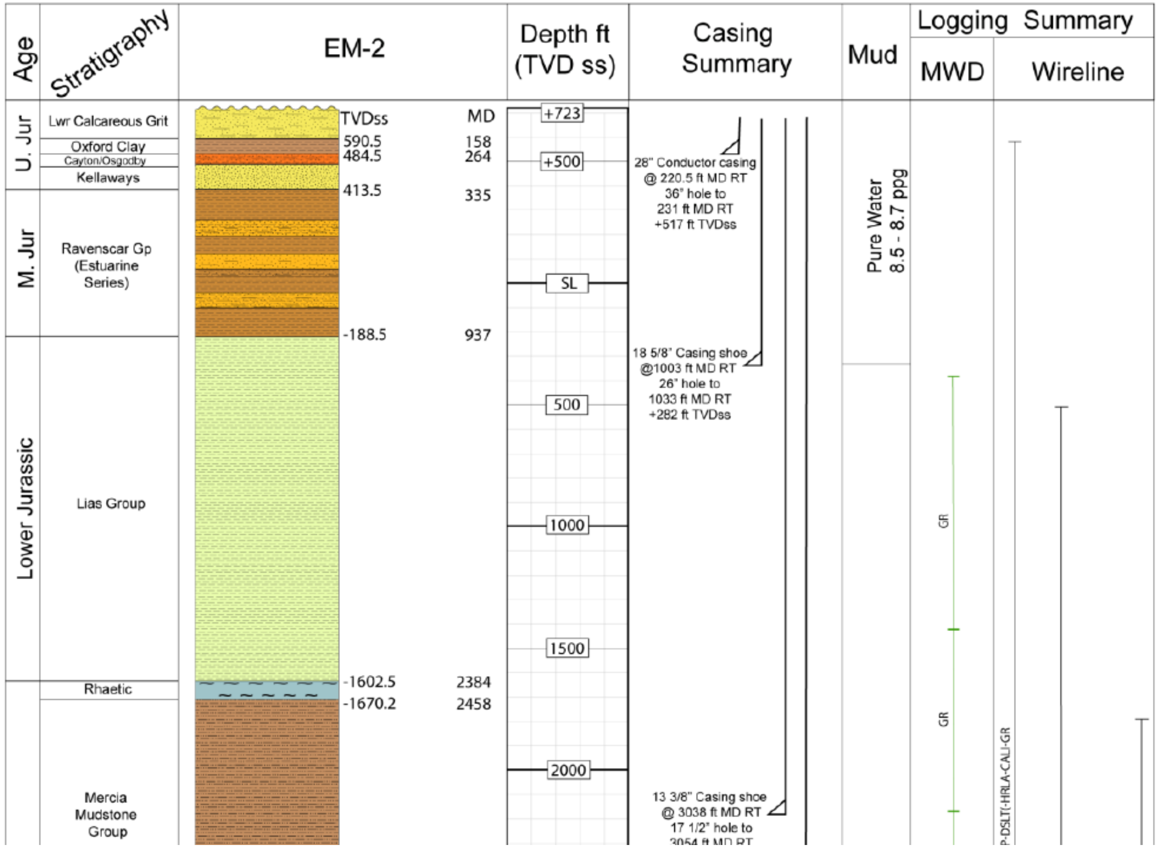


- Europa mapping of the shallow section (Lower Jurassic and Upper Triassic) was undertaken over the Cloughton structure to determine the extent of the shale prone Lower Jurassic (Lias) which is a proposed casing seat in the southern Cloughton appraisal location.
- The updated shallow mapping was used to determine the depth prognosis in the proposed well location.
- There are three key wells that provide a tie to the seismic;
  - Cloughton 1
  - Lockton East
  - Ebberston Moor 2
- Mapping was undertaken in time using all available 2D and 3D seismic. Time grids were converted to depth using velocities from the three wells.

- **Top Whitby Formation at 212’ MD, approximately 200’ below the surface.**
- **Top Redcar Formation at 665’ MD, approximately 653’ below the surface.**

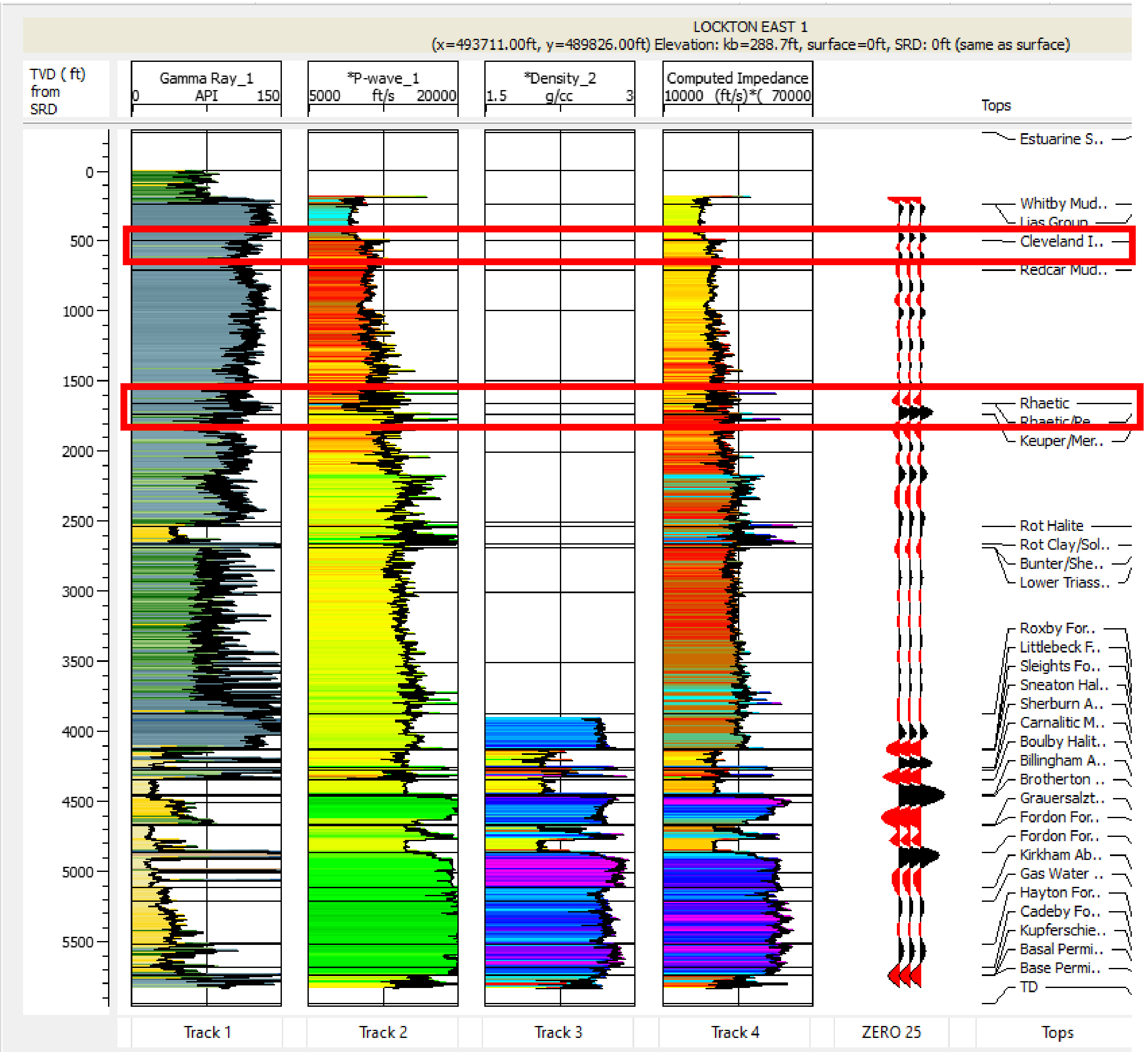
Ebberston Moor-2 Composite Log
Shallow Section





- Mercia Mudstone Group overlain by lower Jurassic (Lias) mudstones overlain by Middle and Upper Jurassic mudstones and sandstones.
- Upper part of the Lias comprises the Whitby Mudstone, Cleveland Ironstone Formation, Staithies Sandstone Formation and the Redcar Mudstone.
- Note only MWD GR in the shallow section.

Lockton East-1
Logs and Synthetic



- Lockton East-1 drilled in 1980 has Gamma Ray and Sonic (P-Wave) over the shallow section.
- It confirms the two main seismic markers in the shallow section are;

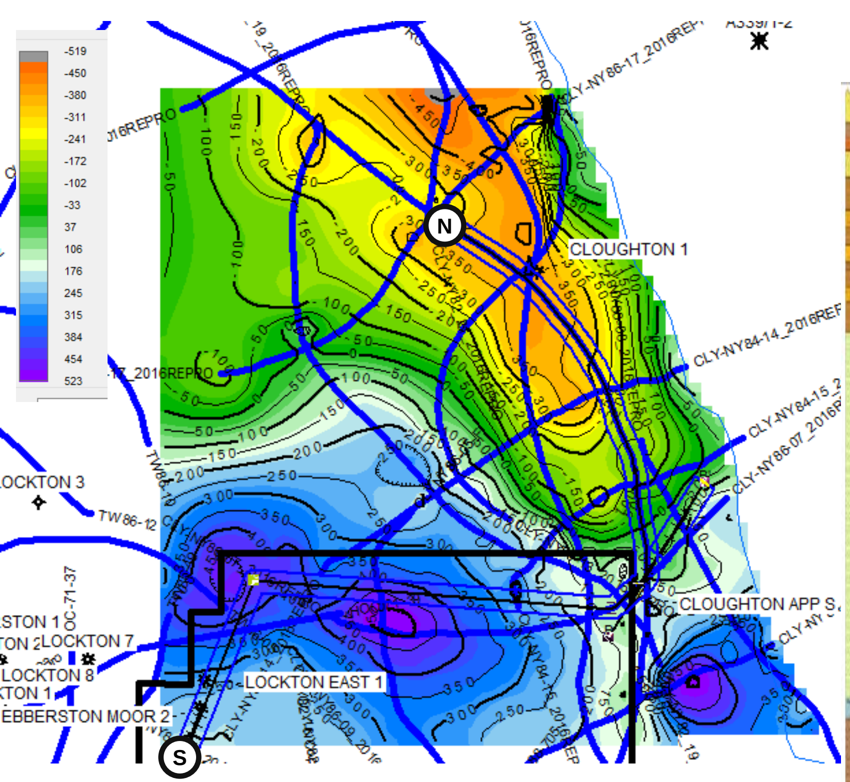
  Cleveland Ironstone Formation

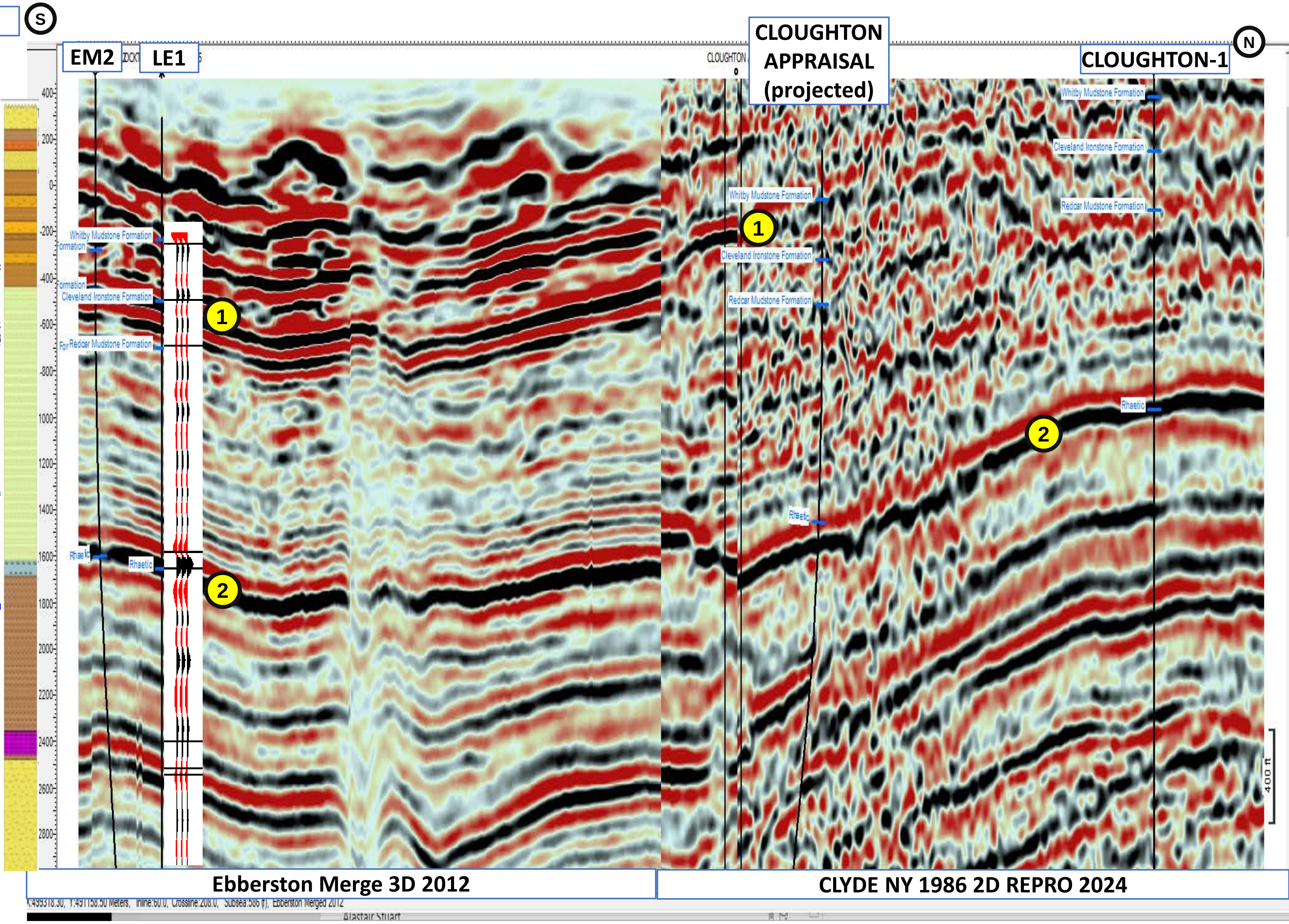
  Top Triassic / Rhaetic

- These are represented by an increase in impedance and strong black peaks.

Arbitrary 3D-2D Depth Seismic and Synthetic Well Tie
EM2 - LE1 - Cloughton Appraisal and Cloughton-1

Top Whitby Mudstone Depth Feet (Europa July 2025)



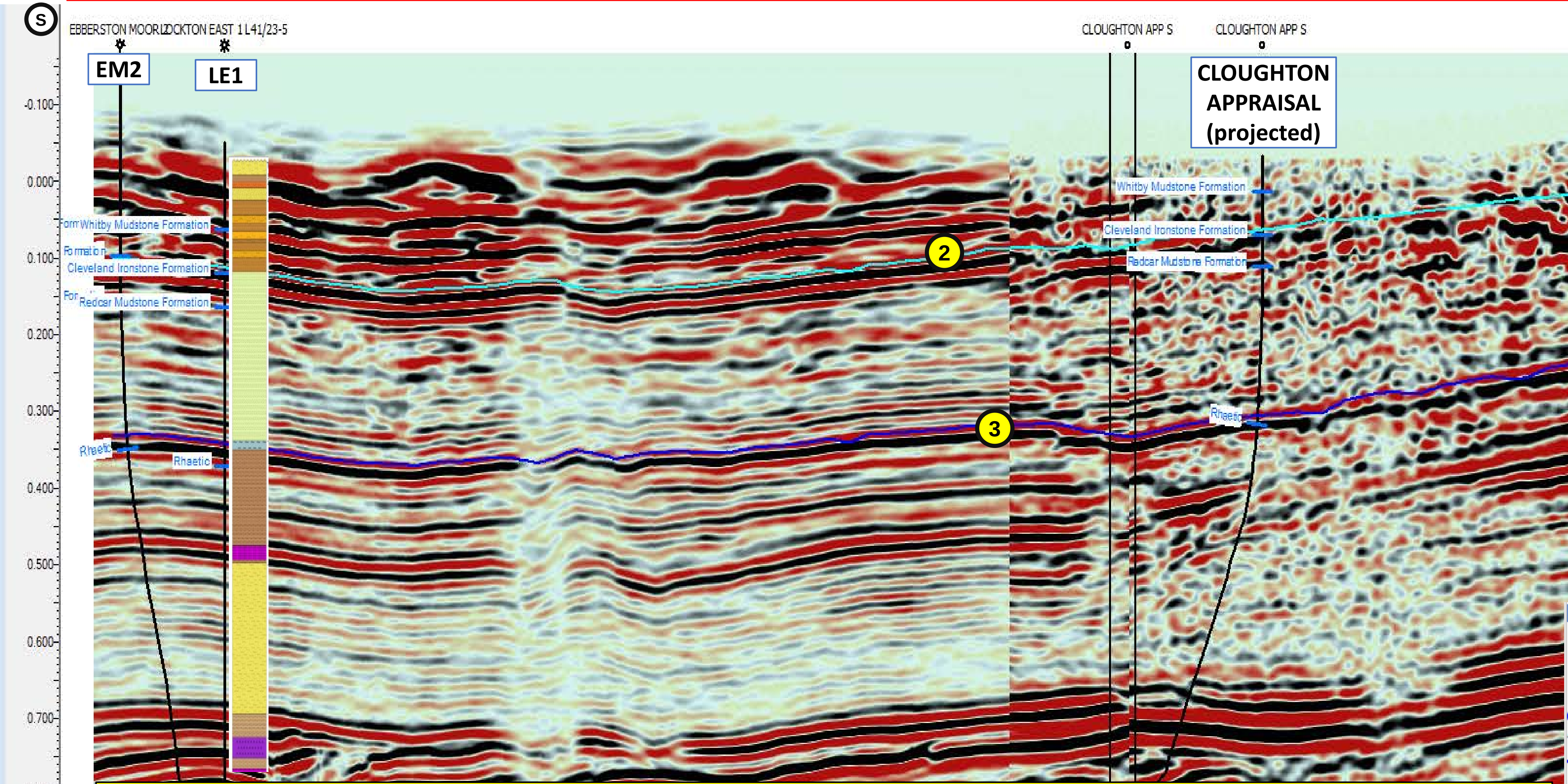


Synthetic track for Lockton East 1 (LE1) well shown on the Ebberston Merge 3D seismic (depth).

1. Top Cleveland Ironstone Formation = black peak = increase in impedance.
2. Top Triassic / Rhaetic = black peak = increase in impedance.

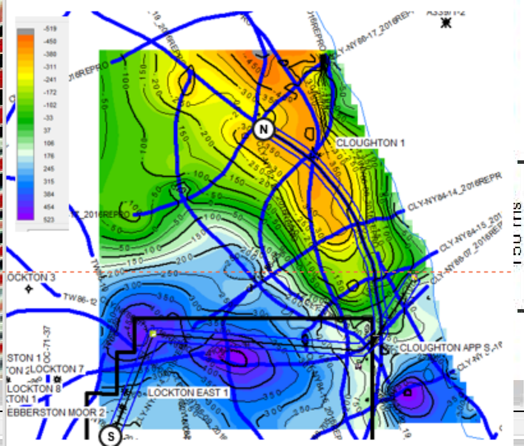
Note the difference in data quality between the 2D and 3D seismic in the shallow section and seismic tie issues between 2D and 3D.

Arbitrary 3D-2D Time Seismic
EM2 - LE1 - Cloughton Appraisal and Cloughton-1

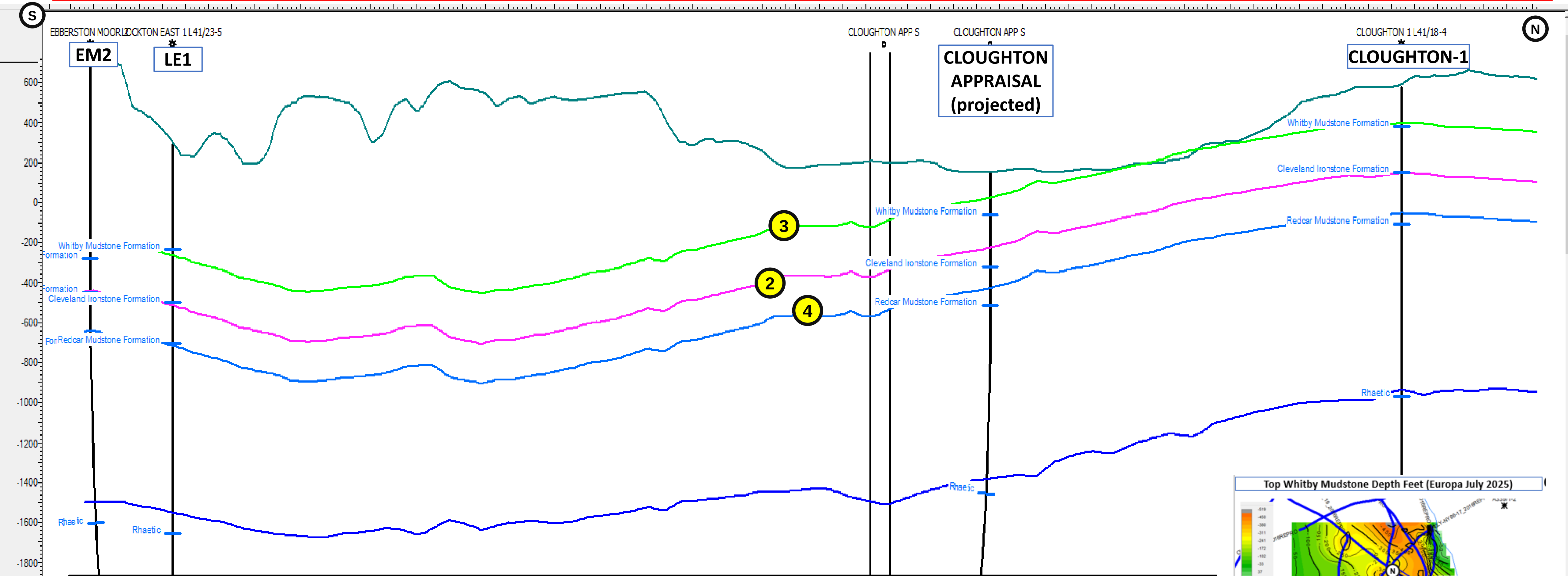


1. Time seismic section shown above. Mapping undertaken in time.
2. Top Cleveland Ironstone Formation mapped on the red trough above the black peak = increase in impedance.
3. Top Triassic / Rhaetic mapped on the red trough = black peak = increase in impedance.
4. Note the difference in data quality between the 2D and 3D seismic in the shallow section and seismic tie issues between 2D and 3D. Time 2D seismic is better quality than the depth 2D seismic.

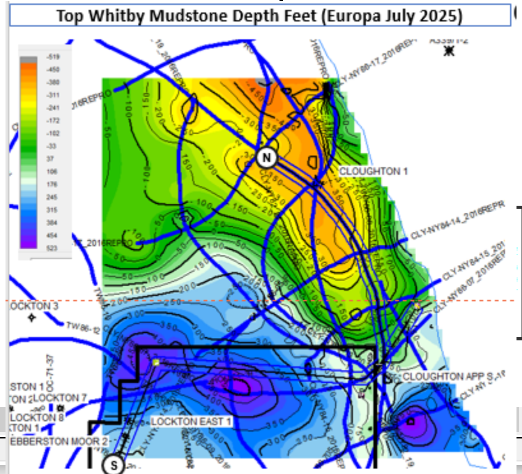
Top Whitby Mudstone Depth Feet (Europa July 2025)



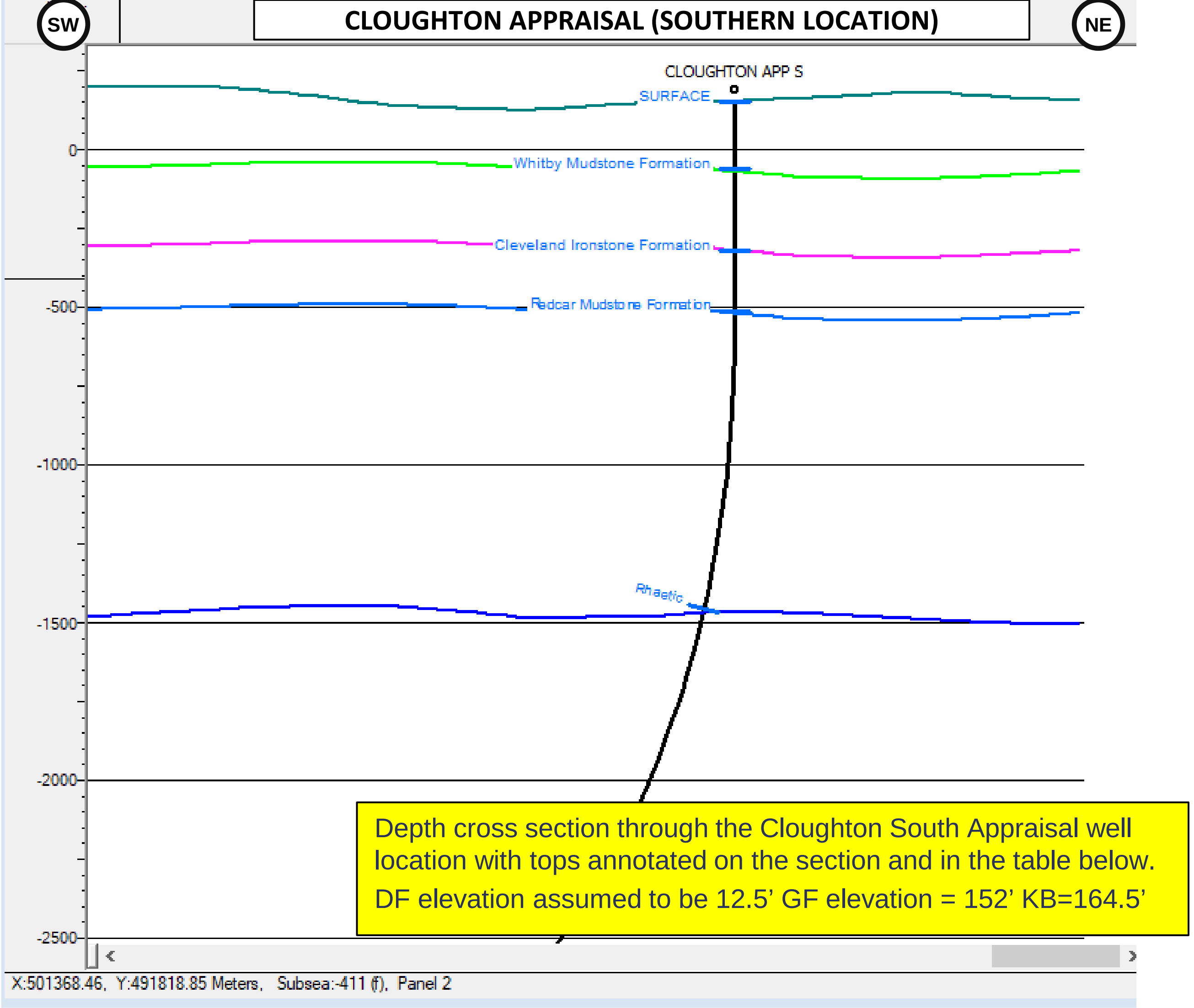
Arbitrary 3D-2D Depth Section
EM2 - LE1 - Cloughton Appraisal and Cloughton-1



1. Depth cross section using previous 3D and 2D section, note Cloughton Appraisal is projected (640m)
2. Top Cleveland Ironstone Formation seismic event converted to depth using a constant velocity of 11/800 ft/sec from SRD (MSL). Corrected to tie the Top Cleveland Ironstone Formation geological tops in the 3 wells with a -150' depth shift. Top Triassic converted to depth using a constant velocity of 9050 ft/sec from SRD (MSL). Provides a good - reasonable tie for the three wells.
3. Top Whitby Mudstone Formation was created by isopaching 250' up form the corrected Top Cleveland Ironstone depth grid.
4. Top Redcar Mudstone was created by isopaching 200' down form the corrected Top Cleveland Ironstone depth grid.

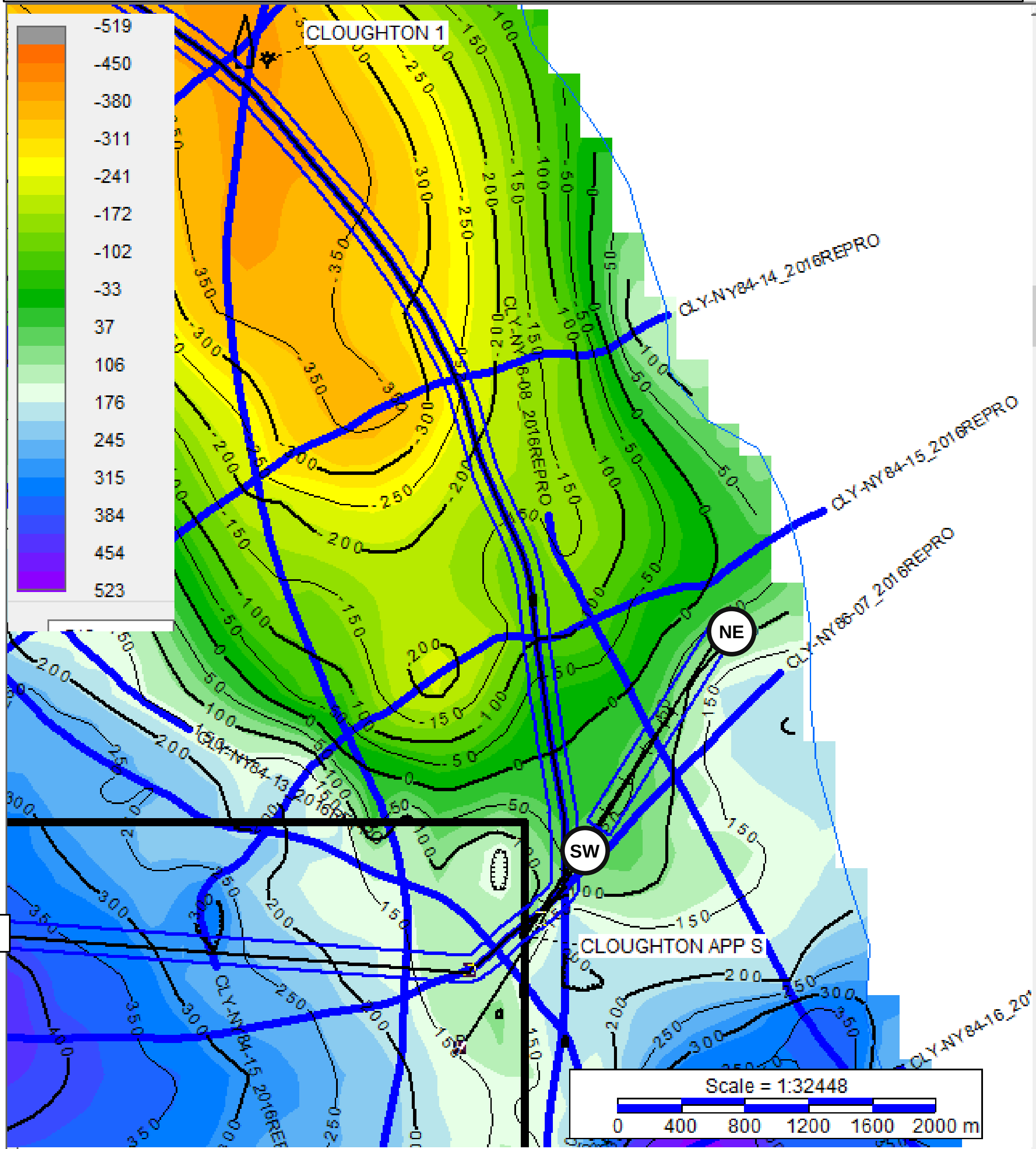


CLOUGHTON APPRAISAL (SOUTHERN LOCATION)



Depth cross section through the Cloughton South Appraisal well location with tops annotated on the section and in the table below.
DF elevation assumed to be 12.5' GF elevation = 152' KB=164.5'

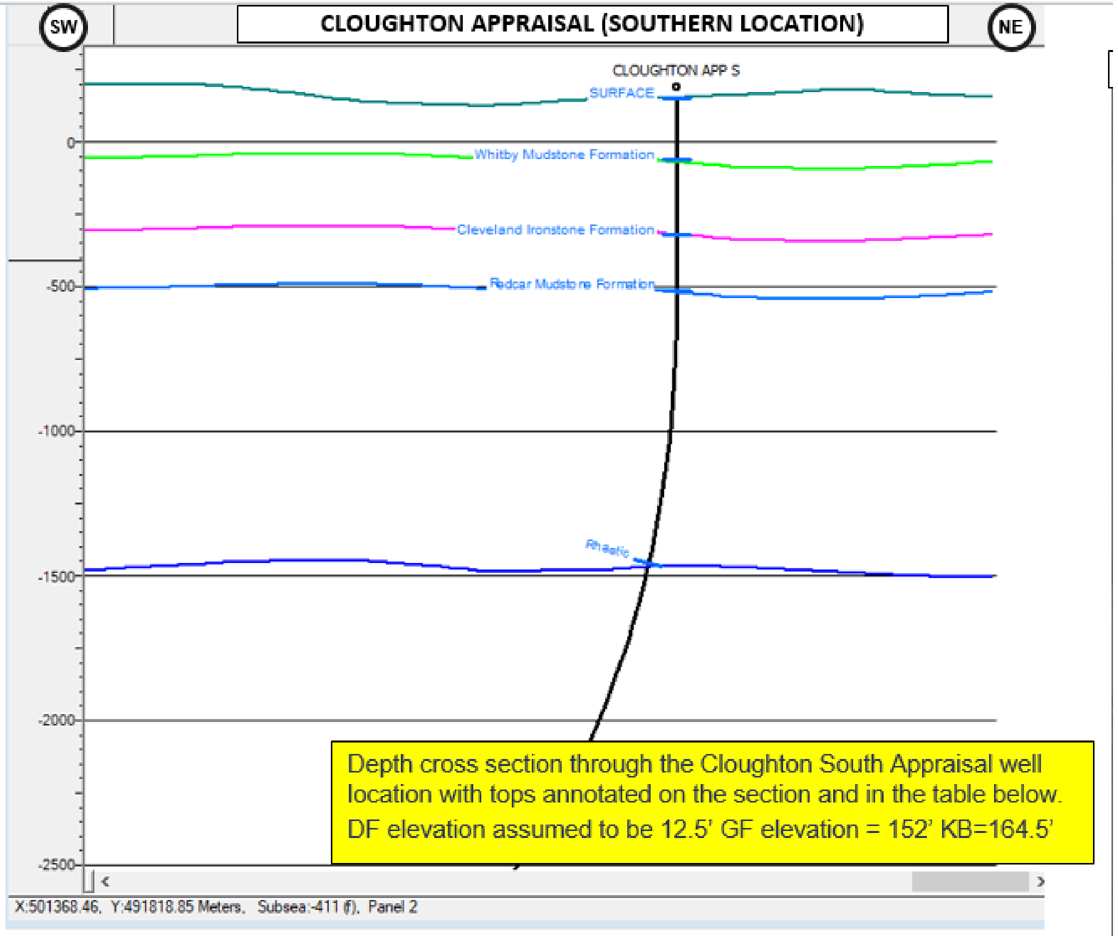
TOP WHITBY MUDSTONE DEPTH (FEET TVDSS)



CLOUGHTON APPRAISAL (SOUTHERN LOCATION) TOPS*

Color	Name	Abbreviation	MD (ft)	TVD (ft)	TVD Seismic (ft)	Subsea (ft)	Time
	SURFACE	SURF	0.00	0.00	-152.00	152.00	-0.03
	Whitby Mudstone Formation	WMF	212.00	212.00	60.00	-60.00	0.01
	Cleveland Ironstone Formation	CIF	472.00	472.00	320.00	-320.00	0.07
	Redcar Mudstone Formation	RMF	665.00	665.00	513.00	-513.00	0.11
	Rhaetic	RF	1629.00	1606.99	1454.99	-1454.99	0.32

Cloughton Appraisal Well
Shallow Mapping Results



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- Europa mapping of the shallow section (Lower Jurassic and Upper Triassic) was undertaken over the Cloughton structure to determine the extent of the shale prone Lower Jurassic (Lias) which is a proposed casing seat in the southern Cloughton appraisal location.
- Base case shallow tops at the Cloughton appraisal (southern location) listed in the table below based on DF elevation assumed to be 12.5' GF elevation = 152' KB=164.5'.
- **Top Whitby Formation at 212' MD, approximately 200' below the surface.**
- **Top Redcar Formation at 665' MD, approximately 653' below the surface.**