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Use of processed resistivity borehole imaging to assess the insoluble content of the massively bedded Preesall Halite NW England

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With the decline of the UK's remaining conventional reserves of natural gas and associated growth of imports, the lack of adequate storage capacity is a matter of concern for ensuring energy security year-round. In a number of countries, subsurface caverns for gas storage have been created by solution mining of massive halite deposits and similar storage facilities are likely to become an important part of the UK's energy infrastructure. Crucial to the economic viability of such facilities is the percentage of insoluble material within the halite intervals, which influences strongly the relationship between cavern sump and working volumes: successful development of these caverns is dependent upon maximising the efficiency of cavern design and construction.
The purity of a massive halite sequence can only be assessed either by direct means (i.e. coring) or indirectly by downhole geophysical logs The use of conventional geophysical logs in subsurface exploration is well established but literature generally relies on a very low resolution tools with a typical vertical logging sample interval of 15 centimetres. This means that such tools provide, at best, a "blurred" view of the sedimentary successions penetrated by the borehole and that discrete narrow bands of insoluble material will not be identifiable or distinguishable from zones of "dirtier" halite with disseminated mud materials.
In 2008, Halite-Energy Group (formerly Canatxx Gas Storage Ltd) drilled the Burrows Marsh #1 borehole and acquired resistivity borehole imaging (FMI) logs through the Triassic Preesall Halite in the Preesall Saltfield, NW England. In addition to near full circumferal imaging capability, rather than a single measurement per increment, FMI logs allows millimetre to centimetre scale imaging of sedimentary features, that is one to two orders of magnitude higher vertical resolution.
After binary segmentation of the FMI images to achieve a simple halite-insoluble ("mud") separation these were subject to a filtering process to develop a detailed understanding of the halite sequence's insoluble content. The results were then calibrated, post-normalisation, by new laboratory determinations of the insoluble content of laterally equivalent samples of core from the nearby Arm Hill #1 borehole. The FMI logs provide a greater degree of resolution when compared to conventional geophysical logs. With the statistical analysis provided by this process, it further enhances the correlation between the logs and core and ultimately, the assessment of insoluble content. Despite the obvious increase in resolution, precise statistical quantification of the success of the borehole imaging technique is somewhat obfuscated by the absence of both FMI logs and continuous core in a single borehole.
The acquisition parameters for these images are at the limits for the tools and therefore more noisy than those acquired in other lithologies or logging environments. The optimum acquisition parameters (in particular gain settings and logging speed), the nature of the filtering required to quantify the insoluble content and the effects of image noise on those calculations are discussed.

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In several countries caverns have been created for gas storage by solution mining of halite deposits. The percentage of insoluble material within the halite is economically crucial as its controls the ratio between cavern sump and working volumes. The halite's purity can be assessed either directly by coring or indirectly by downhole geophysical logs widely used in subsurface exploration. These typically have low vertical resolution (15 cm intervals) so provide a "blurred" view of the sediments penetrated. Discrete narrow bands (>50 cm thick) of insoluble materials are either not identifiable or their top and bases cannot be accurately delineated and are thus indistinguishable from zones of halite containing disseminated mud.

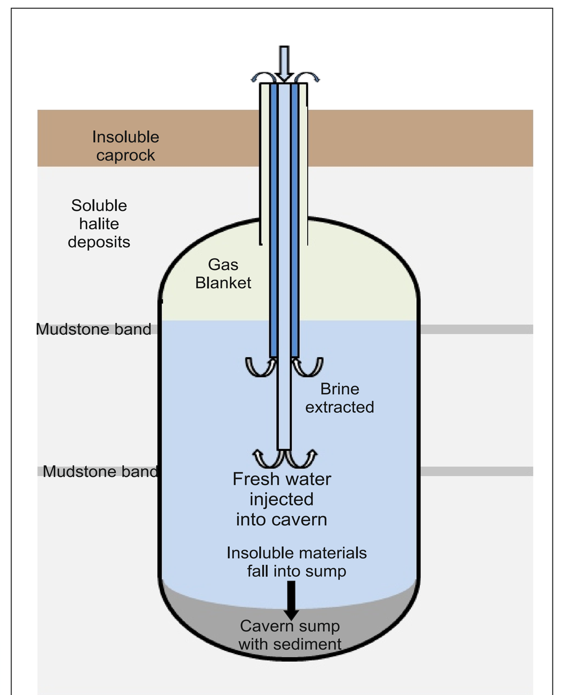


Figure 1: Cartoon of the formation of a solution-mined gas storage cavern

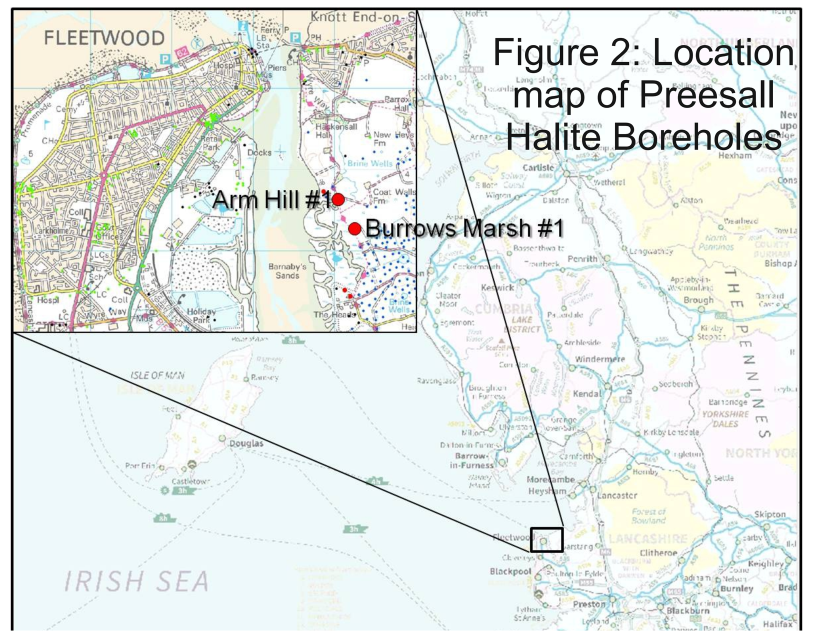


Figure 2: Location map of Preesall Halite Boreholes

Figure 3: Left: FMI Tool showing pattern of button electrodes (Schlumberger, 2002). Centre: Schematic illustration of the projection of planar intersections(bedding and fractures) with a borehole and resultant sinusoidal expressions on FMI images (based upon Gaillot et al. 2007). Right: Example Fracture, Burrows Marsh #1

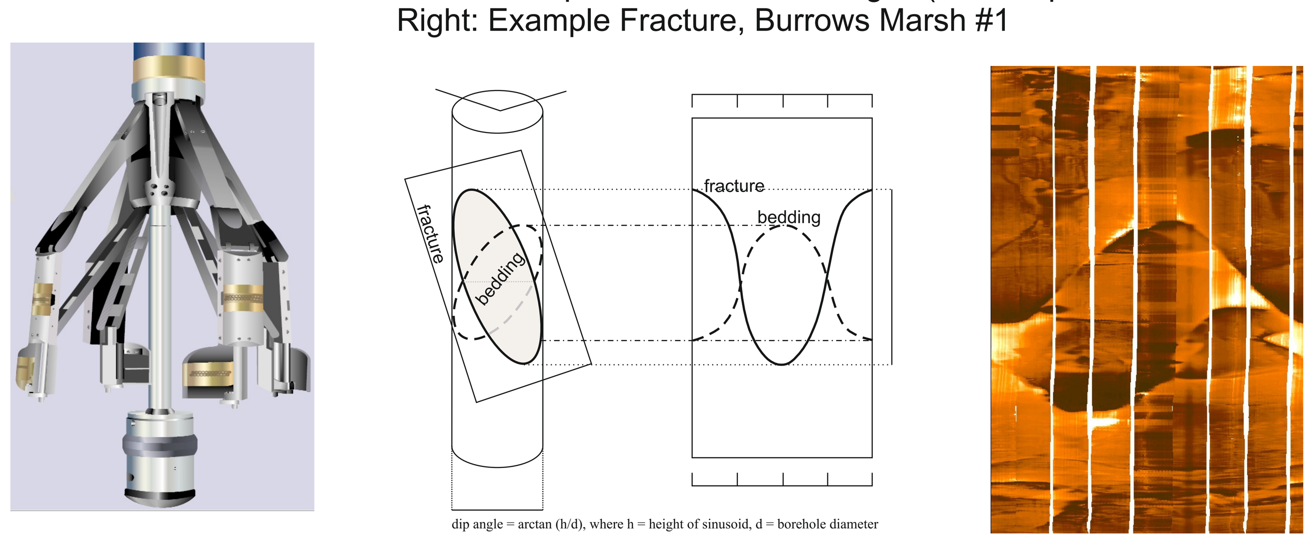


Figure 4: Comparison of Mercia Mudstone Group lithostratigraphy across the United Kingdom. West Lancashire, including the Preesall Halite Member highlighted in green.

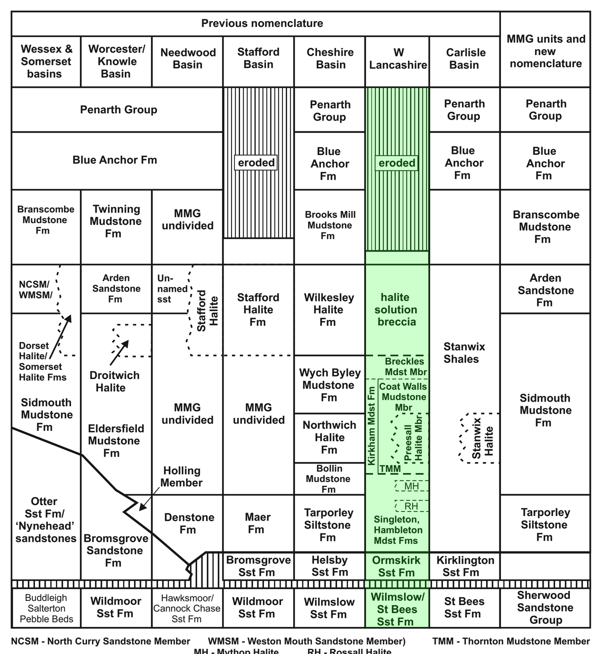


Figure 5: Arm Hill #1 Borehole: Correlation between Gamma Ray logs (API Units) and calculated halite percentage from whole core solution experiments

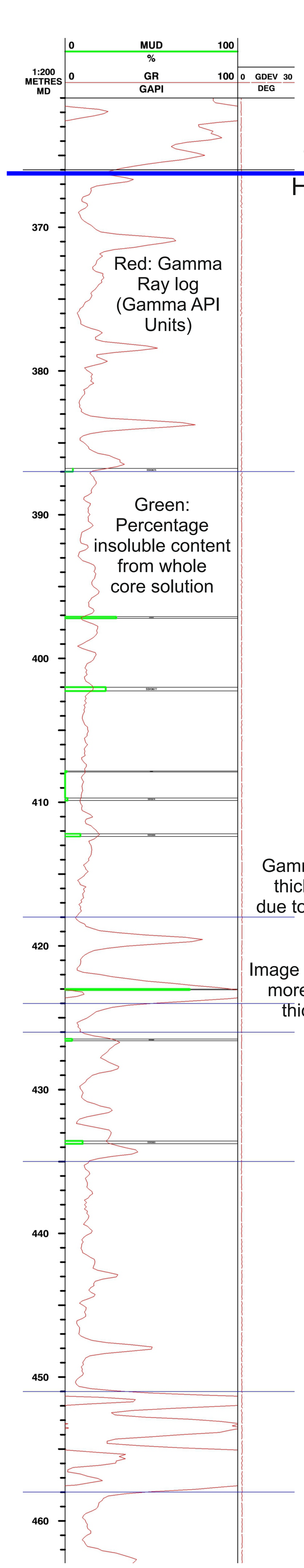


Figure 6: Burrows Marsh #1 Borehole showing (l-r) correlation between Gamma Ray (API Units) log (red curve), image calculated halite percentage (black curve), halite content from core solution experiments in Arm Hill #1 (green histogram) correlated to this borehole and processed boreholes images.

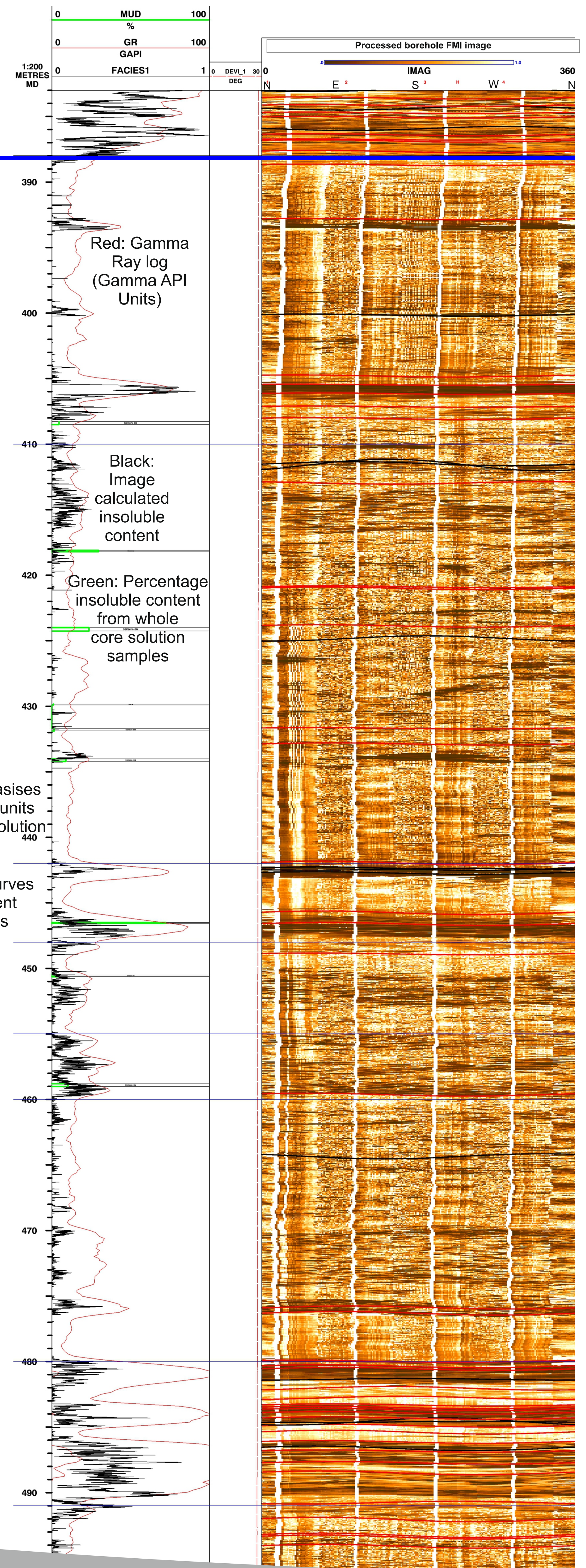


Figure 7: Flowchart for conventional borehole resistivity image processing to produce static and dynamic images for interpretation

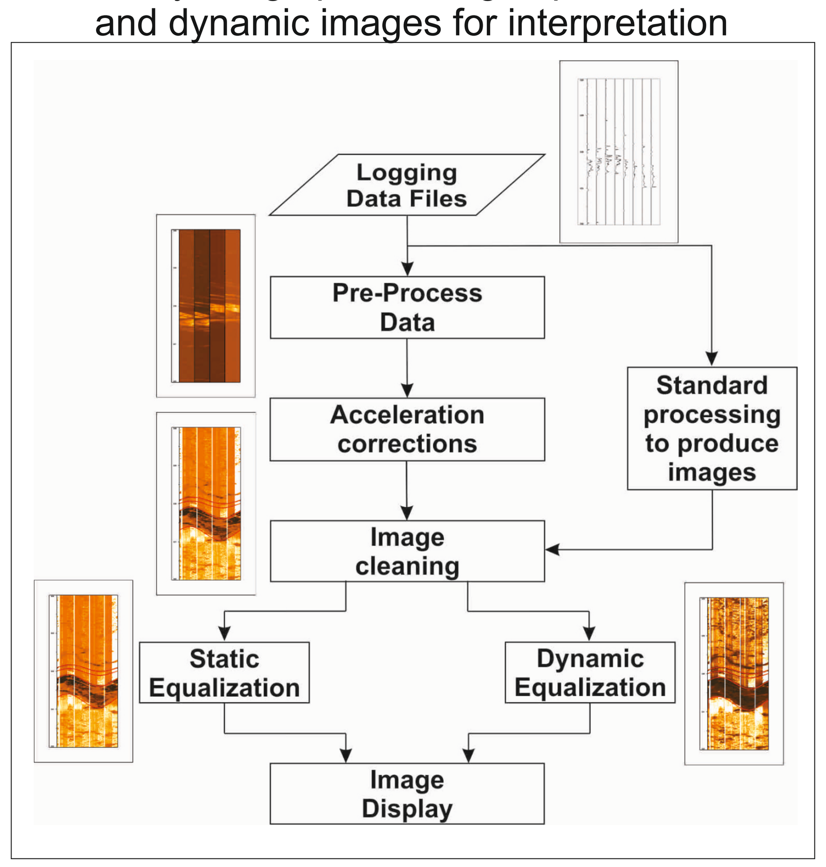


Figure 8: Calculating insoluble content from boreholes resistivity images
A: Flowchart of image processing procedures including filtering
B: Post-filtering monochrome image showing halite (white) and insolubles (black). Images are made up of horizontal strips of pixels with vertical resolution of 4mm
C: Calculation of insoluble content for representative horizontal

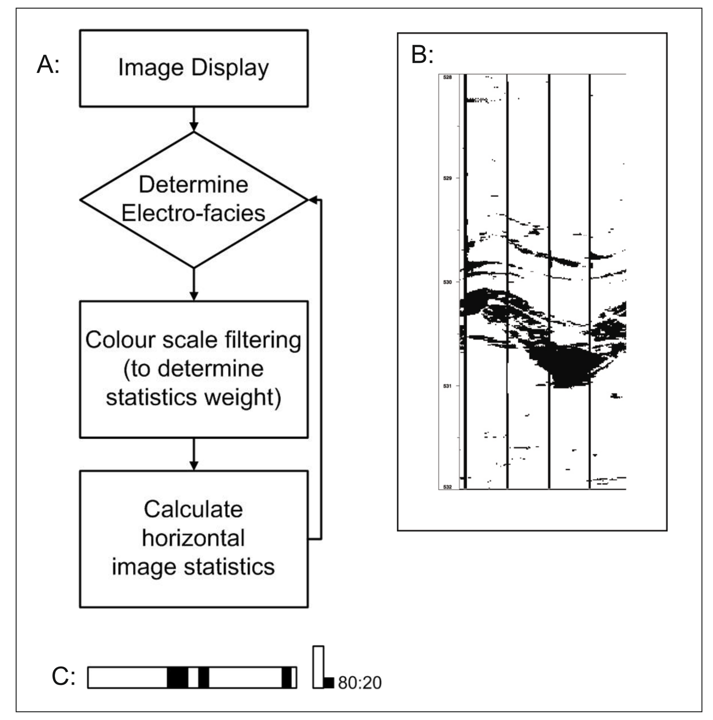


Figure 9: Comparison of images depending on logging speeds and gain setting during acquisition. All FMI datafrom Burrows Marsh #1. Left and centre panel showing static and dynamic equalisation for slow speed and high gain, right panel shows static equalisation high speed, low gain data with much poorer definition.

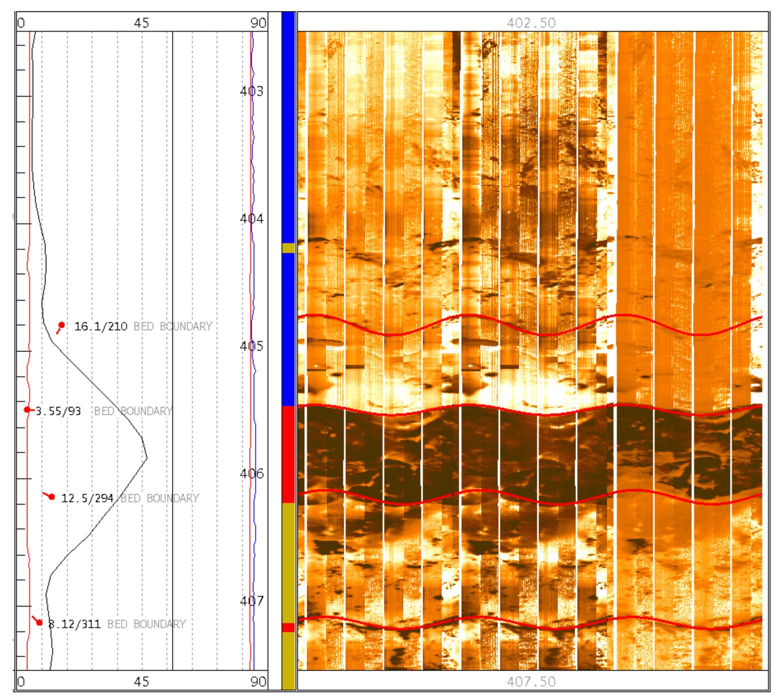
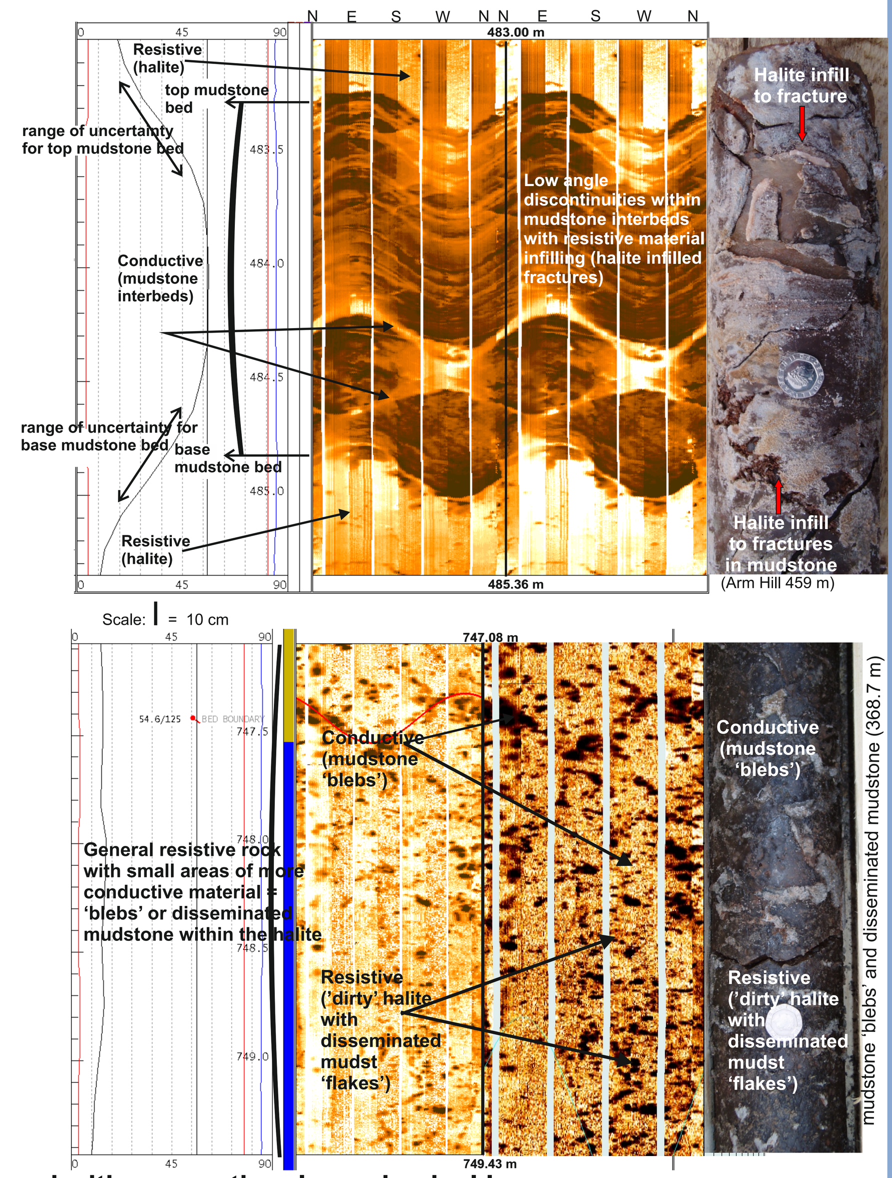


Figure 10: Example images comparing FMI and core highlighting the image resolution



Comparison of using Borehole Resistivity Images compared with conventional geophysical logs

Advantages

- Conventional geophysical logs over emphasise the thickness of mudstone units whereas image logs accurately delineate the top and bottom surfaces of mudstone layers.
- Conventional geophysical logs cannot differentiate between thin mudstone interbeds from zones of halite with disseminated insoluble particulates.
- Together these effects mean that geophysical logs overemphasise two problems in the cavern:
  - the thickness of mudstone interbeds which can lead to ledges and irregularities in the cavern walls and that could represent potential migrations pathways for the gas.
  - the volume of insoluble material which determines the sump volume required to accommodate this.
- The borehole images also show any physical damage to the borehole wall eg washouts at the top of the halite etc which could cause cavern development problems if not properly assessed at the outset.
- Coring is more expensive than acquiring FMI logs so this techniques provides the potential to reduce costs if FMI logs are used to characterise halite beds rather than collecting as many cores

Outstanding Issues

- Borehole image logs cost more to acquire and take longer to process than conventional geophysical logs.
- Acquiring borehole image logs in halite requires slow logging speeds and high gain acquisition settings. These increase the associated noise in the images therefore making calibrating the images more difficult.
- This study area does not have a borehole with both images and core samples of the halite, therefore calibrating the images against insoluble content has proven very difficult the samples are correlated with the images using the gamma logs but the short sample lengths makes perfect correlations impossible).

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