London Petrophysical Society

Seeing is Believing' the applications of well-bore image logs to petrophysics, geology and engineering.

Tuesday 18th June 2013

Agenda and Abstracts

Time	Name	Talk Title	Affiliation
09:00 - 09:20	Registration		
09:20 - 09:30	LPS	Welcome and Introduction	LPS
09:30 - 10:00	Adrian Leech	Imaging - An Introduction and Tool Theory	Gaia Earth Sciences Ltd
10:00 - 10:30	Craig Buchan	Acquiring images whilst drilling or during subsequent logging operations – factors to aid the decision process	Task Geoscience
10:30 - 11:00	Nick Harvey	Comparison of Grainsize, Porethroat and Permeability from Wireline and High Resolution LWD data	Harvey Rock Physics Pty Ltd
11:00 - 11:30	Coffee break		
11:30 - 12:00	Paul Glover	Characterization of non-planar sedimentary structures and resultant palaeoflow directions from borehole images.	University of Leeds, School of Earth and
12:00 - 12:300	Birger Hansen	Characterization of fractured reservoirs by combining image analysis with stress data	Eriksfiord
12:30 - 13:00	Lynda Chebbihi	Applications of borehole image logs integrated with geomechanical study to characterise carbonate reservoirs applied on a Zagros field	Geoscience Limited
13:00 - 14:00	Lunch		
14:00 - 14:30	Andrew Kingdon	Use of processed resistivity borehole imaging to assess the insoluble content of the massively bedded Preesall Halite NW England	British Geological Survey
14:30 - 15:00	Marguerite Fleming	Integration and interpretation of depositional facies from cores and DOBMI; a multi-well study from West Africa	Prolog Geoscience, BHICS Ltd.
15:00 - 15:30	Sally Morgan	Optical, Acoustic and Electrical Image Logs: A lucky dip of scientific applications from the Integrated Ocean Drilling Program	University of Leicester, Geophysics & Borehole Research Group
15:30 - 16:00	Tea break		
16:00 - 16:30	Peter Williams	Wireline Image Log Applications and Case Histories in Unconventional and Complex Reservoirs'.	Weatherford UK
16:30 - 17:00	Robert Laronga	The Complementary Nature Of Borehole Images And Petrophysical Measurements On Core—Seeing Is Believing	Schlumberger
17:00 - 17:30	Johanne Paludan	Fractures on image logs –what we can see and what we can't see	Baker Hughes
17:30 - 17:40	LPS	Closing Remarks	LPS
17:40 - 20:30	Wine and Savouries		

London Petrophysical Society, important notice

Imaging - An Introduction and Tool Theory

Adrian Leech
Gaia Earth Sciences Ltd

A brief introduction to the Physics of Measurement of Imaging Tools as a primer to the rest of the days lectures.

Acquiring images whilst drilling or during subsequent logging operations - Factors to aid the decision process.

Craig Buchan
Task geoscience

Abstract

Borehole imaging is a very well established technology, and a variety of different image measurement techniques can now be used to acquire images either whilst drilling or during subsequent logging operations (the latter being typically, but not exclusively wireline conveyed). These include images based upon measurement of electrical or acoustic properties in the wireline realm. In the LWD realm images include those based upon electrical measurements, and also a range of nuclear measurements including gamma ray and density images. However, different image types do have different sample resolutions, and this will affect their utility.

So, given that not all images are equal, when faced with choosing whether to acquire images whilst drilling or during a subsequent logging operation, what are the factors for consideration, and is there a “workflow” or decision tree that can aid the process? The presentation will aim to outline the advantages / disadvantages of different imaging technologies, and some of the factors that can impact upon deciding whether LWD or wireline images might be best to help deliver the data required or answer a specific question.

Comparison of Grain size, Pore throat and Permeability from Wireline and High Resolution LWD data

Nicholas Harvey - *Harvey Rock Physics Pty Ltd* and
Ray Spicer - *Oil Search Ltd*.

Abstract

The advent of high resolution LWD tools, particularly resistivity tools provides a new form of information which can be used to estimate grain size (particle surface area), pore throat and permeability. The approach used on wireline borehole image data has elicited accurate results and give an insight into grain size, pore throat and permeability distributions within the rock. This paper compares the approach on a Wireline data set and LWD data set over the same interval and comments on the similarities and differences of the approach. We will conclude with a summary of the advantages and disadvantages of applying this technique to LWD data particularly in highly deviated and horizontal holes.

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Characterization of non-planar sedimentary structures and resultant palaeoflow directions from borehole images

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Abstract

Conventional analysis of FMI images for the determination of palaeoflow direction involves the fitting of sinusoidal curves to FMI homo-resistivity intersection curves. This analysis assumes that the sedimentary features are planar. However, if non-planar bedding occurs in the section, the conventional technique can result in large errors in palaeoflow direction due to the unknown offset between the borehole axis and the trough axis. This effect is conventionally accounted for by taking the vector mean of a large set of azimuthal determinations from a depth interval of typically greater than 30 m, and assuming that the errors cancel themselves out. This results in low vertical depth resolutions.

We present an analytical model describing the intersection curves that result from the intersection of a vertical borehole with a mathematically generalized non-planar (hemi-cylindrical) bedded structure. Analysis of the new model shows deviations from sinusoidal behaviour that increases as the dip and the width of the trough/cylinder decreases, and as the intersection offset between the borehole axis and the trough/cylinder axis increases. The deviations imply that if a sinusoidal curve is blindly fitted to such non-planar bedded data, as currently commonly occurs, the dip can be overestimated by as much as 40^{o}, and the azimuth can be in error by $\pm 90^{o}$.

The conventional technique and the new model have been compared to a large number of intersection curves from mixed planar and non-planar FMI data using non-linear fitting and a using range of statistical fitting tests. We have shown that the new technique provides an enhanced analytical capability characterized by (i) greatly improved accuracy in dip and azimuthal determinations, (ii) additional information concerning the width of the trough and the offset of the borehole axis from the trough axis, and (iii) enhanced vertical resolution arising because accurate directional data can be obtained from individual intersection curves. This information enables each non-planar bedded structure to be accurately and uniquely mapped in three dimensions in the sub-surface.

Characterization of fractured reservoirs by combining image analysis with stress data"

Birger Hansen
Eriksfiord

Abstract

Examples from several oilfields are given to show how fractures observed on BHI can be analysed semi-quantitatively to generate fracture porosity curves, elucidate the compression and dilation of fractures in the far-field to fluid pressure changes, and contribute to the completion strategy (casing or openhole, location and orientation of perforations).

Biography

Birger Hansen (PhD geology) has directed teams of borehole image specialists since 1985 in Z&S Geologi and Eriksfiord, and designed Recall and Vinland borehole image and geomechanics applications.

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Fracture and Dynamic Characterisation in a Stress-Sensitive Anticline at Miran West, Kurdistan

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Abstract

The Miran West structure is a NW-SE striking anticline controlled by a SW-propagating thrust with ramp and flat geometry and associated backthrusts. In common with other structures in the Simply Folded Belt it developed during the Mio/Pliocene collision of Arabia with Eurasia and retains an active contemporary stress field. This presentation describes how in-situ stress, litho-mechanical properties, and fracture distributions are intimately linked at Miran. When also linked with dynamic data it is possible to draw important conclusions which help to provide a rationale for development drilling.

Wellbore-scale geomechanical models were constructed to approximately 4km depth within Miran using density logs, leak-off test data, and drilling records to constrain the 3 principal stress magnitudes, and image logs to identify the orientations of the two horizontal principal stresses. These show clear variations of stress regime with depth and with formation, from strike-slip to normal with a wide range of differential stress, together with changes in stress magnitudes and stress axis rotations at active faults. When compared with open fracture distributions identified from the image logs (and calibrated with core observations) it is apparent that strong competent formations behave in a markedly different way to the weaker formations. This is shown primarily by variations in fracture intensity and orientation. Fracture apertures and fracture porosities as calculated from the image logs also reflect these changes. The presentation will show how these observations of the coupled fracture and in-situ stress regime relate to dynamic behaviour as reflected by mud losses and test data.

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

A Kingdon and DJ Evans
British Geological Survey, Keyworth, UK

Abstract

As natural gas from the North Sea is depleted and imports grow, the lack of storage capacity is endangering the UK's energy security. Elsewhere subsurface gas storage caverns created by solution mining of halite deposits have been crucial to solving this. The percentage of insoluble material within the halite is crucial to the economics: 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.

Integration and interpretation of depositional facies from cores and DOBMI; a multi-well study from West Africa.

Fleming, M., Murray, A. and Walker, D.
(Borehole Image and Core Specialists Ltd.)

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Abstract

Borehole image data are commonly acquired in exploration and development wells but frequently sit gathering virtual dust in a company database. Can we put these data to work and add value to geological modelling?

The aim of our current project is to maximise the information derived from a suite of Schlumberger Dual OBMI data, using an integrated and iterative approach linking the borehole image data to high quality core interpretation. We want to extend our understanding of facies type and distribution away from the cored intervals of study wells and stretch that understanding into uncored well sections. Ultimately the image facies may be up-scaled to characterise facies assemblages at seismic-scale intervals (~ 20 m scale) at the well locations. The data can also be used to understand sub-seismic sand body azimuth variability and to assign more sensible geometries to these sand bodies.

Can we improve our understanding of the rock succession beyond net to gross? By carefully deriving the image facies, particularly with good core control in a subset of wells, it may be possible to understand the character of sandstones that are present, i.e. mudclast-rich, cemented, well-bedded or massive, pebbly or conglomeratic. We can also extend our understanding of mud-prone sections to analyse the distribution of thin beds and discern whether the mudstones have undergone syn-sedimentary deformation. This information can help the geologist visualise spatial facies trends. In addition to facies data, bedding patterns derived from precisely constrained manual pick data can yield information on sediment dispersal, migration of depositional bodies, sand-body geometry and soft sediment deformation.

How do we meet these project aims? Strict quality control and processing of the borehole image and ancillary data is essential; the identification and elimination of image artefacts is imperative to produce high quality images for interpretation. Picking is undertaken manually; geological features (bedding, fractures) and *in situ* stress indicators are oriented from the images. The key to producing a high density, geologically reasoned pick set is an iterative process whereby the interpreter refers to the open-hole log suite, core data and both statically and dynamically normalised image data. Consistency between interpreters is achieved by rigorous cross-checking. Manual zone-bar picking of image facies is also an iterative process. The use of available core data, log suites and bedding dip patterns are vital in defining the image facies suite. Identification of image facies involves 'training' the interpreter's eye to the image character and petrophysical response of a facies and extrapolating the image facies interpretation into uncored intervals. Identification of image facies is interpretative and the geological experience and consistency of the interpreter is

critical to producing a high-quality dataset. Up-scaled image facies assemblages coupled with bedding dip patterns are additional geological data that can be superimposed on seismically derived attribute maps or extractions in order to reduce uncertainty in subsequent reservoir modelling.

Optical, Acoustic and Electrical Images: A lucky dip of scientific applications with the Integrated Ocean Drilling Program

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Abstract

The Integrated Ocean Drilling Program (IODP) makes use of a wide variety of imaging tools. These range from super-slimline acoustic and optical tools, to older slimline and more modern standard oilfield technologies. Data is used to examine lithostratigraphy, structure (bedding, cross bedding/laminations, fractures) and for the assessment of regional stresses. Presented here are a few examples of the way in which image data has been utilized on IODP projects in a number of different geological formations:

-The utilization of optical images to help establish the distribution of coral types/species as well as to gain a better appreciation of the true core recovery in these sometimes very porous formations (IODP Expedition 310).

-Acoustic imagery to pick out key boundaries sometimes not recovered in the core due to dramatic variability in the lithology (IODP Expeditions 325 and 330).

-Electrical images, both wireline and LWD, have been used for picking out fracture orientations and borehole breakouts (IODP Expeditions 330 and 343).

Wireline Image Log Applications and Case Histories in Unconventional and Complex Reservoirs

Peter Williams
Weatherford

Abstract

Micro-resistivity imager tools were introduced to the industry over 30 years ago.
They have broad application in geological, petrophysical and geomechanical studies.
Applications include:

- Visualizing complex structures
- Identifying faults and fractures and their orientation
- Determining structural dip and sedimentary features
- Defining crossbeds, thin beds and net-to-gross ratio in sand-shale sequences
- Identifying sand-shale facies and sand counts
- Evaluating secondary porosity
- Depth-matching and orientation of cores
- Structural and breakout analysis
- Image petrophysics analysis
- True-vertical-depth (TVD) analysis

Logs from both conventional and unconventional reservoirs demonstrate the robustness of the data over a broad range of common environments. Results have been applied to the description of clastic and carbonate reservoirs, natural fracture identification, hydraulic fracture design, and new well placement. Applications and case histories are presented from operations around the world.

Biography

Peter Williams is a Senior Technology Champion for Weatherford's Wireline Services product line and is based at the Research and Development centre in the UK. He has over 37 years of industry experience in a variety of technical, sales and managerial roles within the wireline service industry including general field engineer, training manager, operations development manager and business development manager. Educated at Manchester University, UK, he is a Chartered Engineer and a member of the Energy Institute, Society of Professional Well Log Analysts and Society of Petroleum Engineers.

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The Complementary Nature Of Borehole Images And Petrophysical Measurements On Core—Seeing Is Believing

Robert Laronga,[1] Peter Tilke,[2] and David Allen[1]
1. Schlumberger
2. Schlumberger-Doll Research

Abstract

We examine the complementary and often seemingly contradictory relationship of continuous logs to measurements and observations based on continuous conventional cores and/or sidewall cores. High-resolution borehole images merit special attention in this regard, as their availability and timely interpretation at various points during the overall acquisition-interpretation-subsurface integration workflow can reconcile differences by significantly impacting:

1) Where and how much we sample.
2) Representation of significant Petrophysical Rock Types present
3) Rate of core recovery.
4) Tie to log data, both in depth and orientation.
5) Expectation of how closely log and core data should match each other.

Most geoscientists think first of the conventional core as 'calibrating' the features that are seen and/or interpreted in the images. This is certainly true in applications such as net-to-gross determination or sedimentological studies, and a brief review is provided here.

Conversely, it is well-established that borehole images add value to conventional core by providing a precise depth tie and by orienting features observed in the core. A recently-introduced technique quantifies heterogeneity from the image at a given depth to predict its impact on measurements made at plug scale. Used together, these techniques reconcile differences between core and log data at the integration phase.

Sampling conventional core for SCAL work, we stand before the slabbed core and select the most representative locations. As larger sidewall cores suitable for SCAL work are now a reality, we demonstrate that interpreted petrophysical logs and images made available in a timely manner can largely fulfill the same role. Analysis of images performed before core acquisition aids in developing a strategy for representative sampling, and may in some cases also be useful for improving recovery.

Images acquired after sidewall coring serve not only to precise the tie between core and log, but may also aid in understanding where and why recovery was unsuccessful. They also aid in understanding whether or not samples successfully acquired are representative of reservoir properties at large.

A number of case studies are presented demonstrating the above applications, with the finding that borehole images are an indispensable complement to core.

Fractures on Image logs –what we can see and what we can't see

Johanne Paludan
Baker Hughes Incorporated, Hassi Messaoud, Algeria.

Abstract

A good "conceptual model" is an important prerequisite for building an accurate fracture model, which may be used for reservoir simulation, well planning and long term field development. Borehole image logs are an indispensable source of information in this process, but must be used in conjunction with information from other sources, including core, dynamic data, outcrop equivalents and seismics. The amount of available data of course varies from case to case, but in some studies image logs are practically the only source of information. In this presentation we aim at illustrating how a conceptual model may be built based (almost) entirely on image data, especially if the tool combination is optimised to fit the fracture characteristics. We also show, however, how failing to include information from other sources may result in an oversimplified model, which may not reflect the actual properties of the reservoir. Examples from two fractured reservoirs in Algeria are used for illustration.

The Cambrian Ra reservoir is a fluvial sandstone deposit with low matrix porosity. Although natural fractures have long been recognized to play an important role in enhancing permeability, the fracture system remains relatively poorly understood. Image logs have been used for identification of fractures in both vertical and horizontal wells for many decades. However, due to the use of oil based mud, only acoustic images could be acquired up until 10 years ago. The introduction of the oil based resistivity imager made possible the acquisition of dual image logs (acoustic and resistivity images logged simultaneously). This revealed that the fractures detectable on the acoustic image represent only a small subset of the entire fracture population. This is because fractures are generally cemented to various degrees and only the open segments tend to be visible on the acoustic image. The cement is mainly conductive, probably including pyrite as well as diagenetic clay, which generate a strong conductive response on the resistivity image. Open segments, filled with resistive mud, only show as resistive when the aperture is very wide or the fracture is completely free of mineral cement. Thus, the dual image is necessary to identify both open, potentially flowing fractures and cemented fractures, likely to impede flow. Figure 1 shows an example, in which both types of fractures are present. The spatial distribution and general image characteristics suggest that the fracture system is relatively simple, with one generation of strike-slip shear fractures, which are closely related to the regional fault system. The hydraulic properties are likely to depend on the degree of cementation, which can be estimated based on image characteristics for each logged well, while the factors governing cementation are not clear. Hence "sweet spots" with high densities of open fractures are difficult to predict.

The Ordovician "Unit IV" reservoir is a complex system of glacial outwash deposits with varying reservoir quality, in which natural fractures are also believed to significantly enhance permeability. A detailed study of core was conducted in conjunction with an image-based fracture study. In this field image logs were restricted to single water based resistivity images. The core observations revealed a complex fracture history, including early soft sediment shear zones and three separate generations of tectonic fractures. These were distinguished based on cementing minerals, cross-cutting relationships and kinematic indicators, details which were not detectable on the image logs. Pyrite cement is common, which makes the fractures indistinguishable from open ones on the water based resistivity

image. The images all show a high number of drilling-induced fractures, including both simple tensile cracks and larger bit-related fractures. The latter could not be distinguished from natural fractures on the image logs, but core observations showed evidence of a natural origin for some. This suggests that a fourth generation of fractures may be present, which are open and aligned with the current maximum stress. These are likely to be widened and expanded by the drilling process, which would make them almost indistinguishable from induced fractures on the log. Thus, without core observations the one set of fractures which contributes the most to production could be almost or completely overlooked, as the fractures are camouflaged by drilling induced fractures.

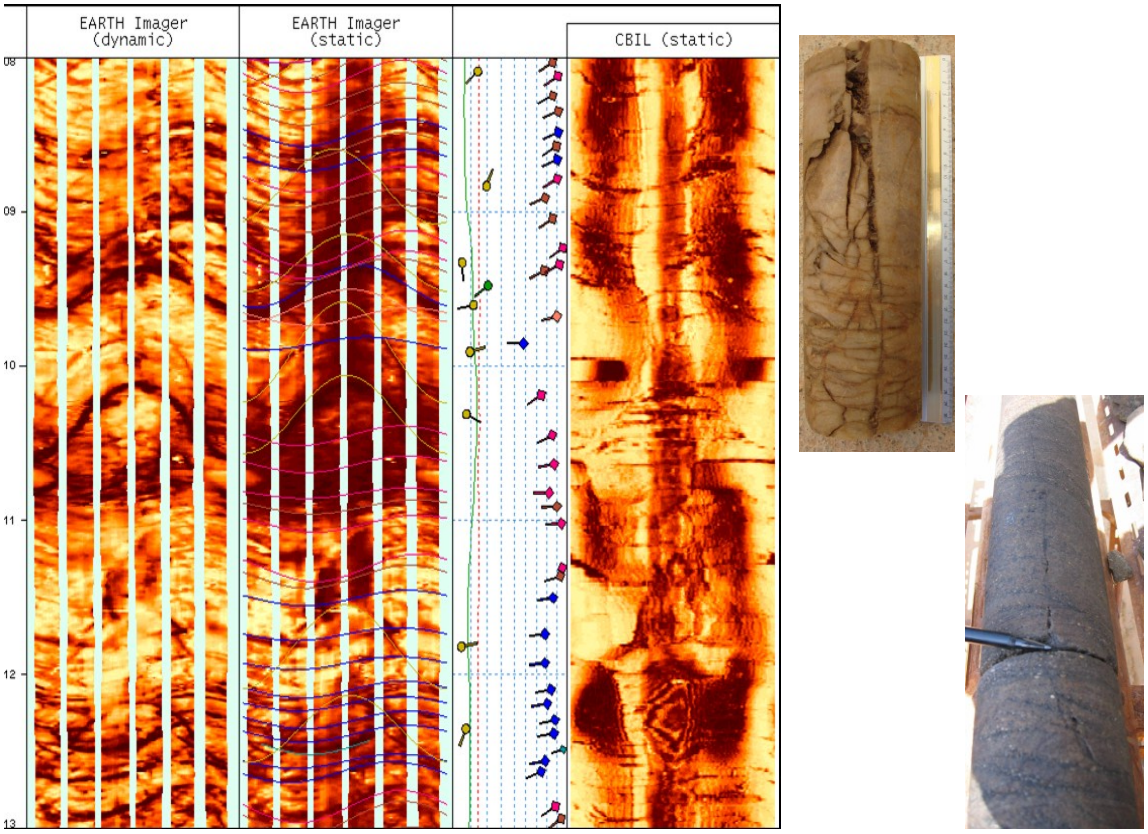

Figure 1 – Example of fractures seen on a dual image, consisting of EARTH (oil based resistivity) and CBIL (acoustic) from a horizontal wellbore in the Cambrian Ra reservoir. Note how the resistivity image shows a large number of fractures, only a subset of which is visible also on the acoustic image. Fractures are partially cemented with electrically conductive minerals. The ones visible on the CBIL are believed to be partially open. Equivalents from a vertical core are shown on the right. Top: Dominantly open. Bottom: Dominantly cemented.

Biography

Johanne holds a Ph. D. in geology from the University of Aarhus, Denmark. She joined the Z&S Geology consultancy in Norway in 1997 and has since worked as a borehole image and geomechanics specialist in Western Atlas and Baker Hughes in Norway, Italy and the UK. She is currently based in Hassi Messaoud, Algeria, and is one of the Baker Hughes global subject matter experts on imaging and geomechanics.