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Core Values: the Role of Core in 21st Century Reservoir Characterisation

4-7 May 2021

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Core Values: The Role of Core in 21st Century Reservoir Characterisation

4-7 May 2021
Virtual Conference, Zoom, BST

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4th May 2021
Session one: Geological Challenges

KEYNOTE: Core beliefs, Core Strengths, Core values:

Bruce Levell
University of Oxford

The subsurface gesoscience community is in general convinced of the value of core. Leaving aside the operational and cost issues this presentation highlights through examples the strengths and weaknesses (under-usage) of core material. The examples chosen are those familiar to the author.

Core data are probably the only subsurface data that can illuminate totally unexpected rocks! The Neoproterozoic plays in Oman, and the Early Cretaceous pre-salt play in Brazil are two examples where early and extensive coring was the only way to establish the nature of the reservoirs and to build predictive facies models. These were both situations where there was no usable depositional model in the literature. Log, seismic, and well test data without core were simply confusing. Sidewall samples could only hint at the strangeness of the rocks. In such cases there is great value in early coring, even though predictive facies models still take a long time to build.

Core data are essential for the calibration of petrophysical analysis and to ensure that special core analysis and reservoir data are at least reasonably representative of the rock succession. The discipline interface between petrophysics and reservoir geology is often an issue in using core data to extend beyond calibration of reservoir parameters to enabling facies identification from logs. Image logs, with their geometric information, can often provide the link from core to a log-based facies scheme. Integrative geologists who have the confidence to work with both sedimentology and petrophysics (as well as seismic) are essential. Examples from the Neoproterozoic carbonates and Pennsylvanian glaciation of Oman illustrate this point.

Core data can provide rapid insight into the nature of a depositional system. Examples include turbidite plays and injectites in the North Sea Palaeogene for example. However, the drive to provide a unique depositional interpretation of every bed in a core is dangerous. This is especially the case with spot cores, which are almost always a false economy. In my experience most cores contain some element which allows facies interpretation of environment with a reasonable degree of certitude, given the context. Mostly this is because full genetic sequences are not sampled in the short lengths available. Gaps in the record are ubiquitous. Sharp bed contacts may or may not represent significant time. An illustrative example are the early cores from the Upper Jurassic Troll field Norway.

An extreme example of tough decisions and of the need to assess the strengths and limits of core data is set by the rationing of core-retrieval and return during the Mars sampling missions, starting with the launch of the core-and-cache Mars 2020 mission.

Value of Core For Reservoir Deliverability Prediction in Low Permeability Sandstones: Barik Formation, Khazzan Field, Oman

Martin Wells, Nigel Clark, Khalil Al Rashdi

[1]bp

The giant Khazzan gas field, onshore Oman, has been under development since 2013. The field is currently producing 1.5 bcfd gas from the Cambro-Ordovician Barik Formation. The 80 m thick paralic reservoir is 4.5 km deep and has undergone complex stages of diagenesis, hydrocarbon charge and structural regime change. Reservoir quality (RQ) is typically low (average porosity 6 pu, average permeability 1 mD) but locally exceeds expectations given the burial history (reaching up to 12 pu and 100 mD). This RQ variability and complexity makes reservoir deliverability (RD) one of the largest subsurface uncertainties, impacting development area, number and type wells, and well productivity, ultimately affecting the project economics.

Core was at the center of an integrated subsurface study of the Barik, also utilising outcrop, seismic, petrophysical and production data, to reduce RQ and RD uncertainty and increase reservoir development efficiency. Burial history modelling, petrographic analysis, high pressure mercury injection, and minipermeameter data were key techniques used to unravel the RQ story.

As expected, given the age and relatively deep burial of the reservoir, compaction and cementation have strongly overprinted primary depositional facies. Quartz cementation, followed by feldspar dissolution and dolomitization, are significant but variable. Detailed petrographic analysis reveals that quartz cementation is controlled by grain size, compaction, and feldspar content. Significant quartz cementation is observed adjacent to mudstones, with generally lower abundances at the centre of thick sandstones. Minipermeameter data confirms that distance to mudstone, or sandstone thickness, is an important control on RQ. Using normalized gamma ray log data, total and mean individual sandstone thicknesses were calculated for every well and compared to well dynamic behavior which showed a positive correlation.

The resultant reservoir deliverability map of the Barik Formation is consistent with the depositional environment, diagenetic understanding and well performance. Core was essential to building a robust, high resolution understanding of a complex reservoir, which could then be tested against dynamic data. This understanding is impacting development drilling and reservoir geomodelling to predict life-of-well production rates.

Value of Core in Mature Field Development – Examples from the UK North Sea

R. H. Worden (University of Liverpool), S. Kelly, P. Mc Ardle (EnQuest)

Core based studies have had material impact on the understanding of a number of late-life mature North Sea hydrocarbon fields. These studies, often completed as MSc projects, have included sedimentological, diagenetic and reservoir quality focused evaluations of core aimed at improving conceptual models that can be utilized in reservoir modelling and field development infill and workover evaluations. Most of these studies have been undertaken on old core samples collected in the 1980s and 1990s. In some regards, the importance and value of these old cores is only now being appreciated when we are trying to extract as much remaining oil as possible from the sub-surface.

A variety of core-based techniques have been used including core logging and description, optical microscopy and petrographic studies, isotope analyses, XRD and SEM-EDS (QEMSCAN)-based mineralogy, portable-XRF, NDTr and NDT geochemical analysis, as well as image analysis of grain size and texture.

Individual core-based studies have included the characterization and distribution of calcite cements and their impact on acoustic seismic properties and reservoir quality distribution in Brent reservoirs (Heather), understanding the chemistry, mineralogy and sedimentology of low-permeability horizons with the Etive Formation (Thistle), and facies and reservoir characterization of Magnus Sandstone Member and Lower Kimmeridge Clay Formation reservoirs (Magnus).

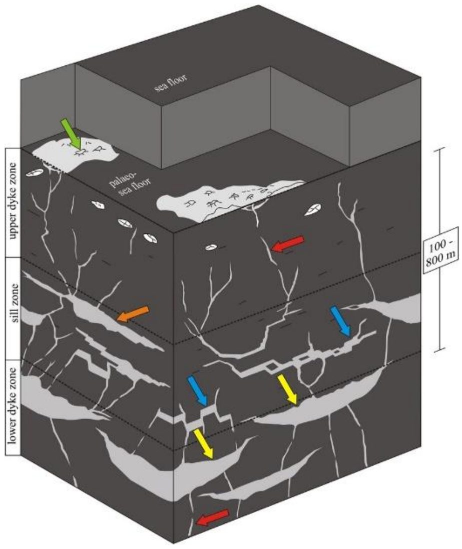
These new and focussed reappraisals of core demonstrate the dual value of core-based studies to:

1) improve the understanding of producing hydrocarbon reservoirs, leading to improved productivity and efficiency,
2) further our general knowledge and understanding of clastic sedimentology and diagenesis using rich and diverse core based datasets backed up by substantial wireline and seismic datasets.

Turbidite or injectite? The importance of core for correct interpretation of reservoir geometries

John Cater,
Petrostrat

Seismic-scale injectites commonly comprise large volumes of clean, high quality sandstone sealed within and/or charged from shales. Spectacular examples include Alba (UK) and Volund (Norway), together with more recent discoveries at Catcher (UK) and Agar/Plantain (UK/Norway). This presentation reviews the characteristics of injectites and shows that core is vital to correctly interpret their origin and predict reservoir geometry and performance.
Many seismic scale injectites have a distinctive 'Loch Ness Monster' shape in cross section and 'inverted shepherd's hat' 3D geometry. As a result they cross-cut the host rock at a variety of angles. *Oblique injectites* (clastic dykes) are readily identified on seismic and in core, due to disconformable contacts with the host lithology. Volund is a classic Loch Ness type that illustrates this. *Conformable injectites* (clastic sills) are less easily distinguished from *in situ* sandstones. This is seen in Catcher, where sands were injected across a fault. Cores from both types of injectite are illustrated and discussed in this presentation.



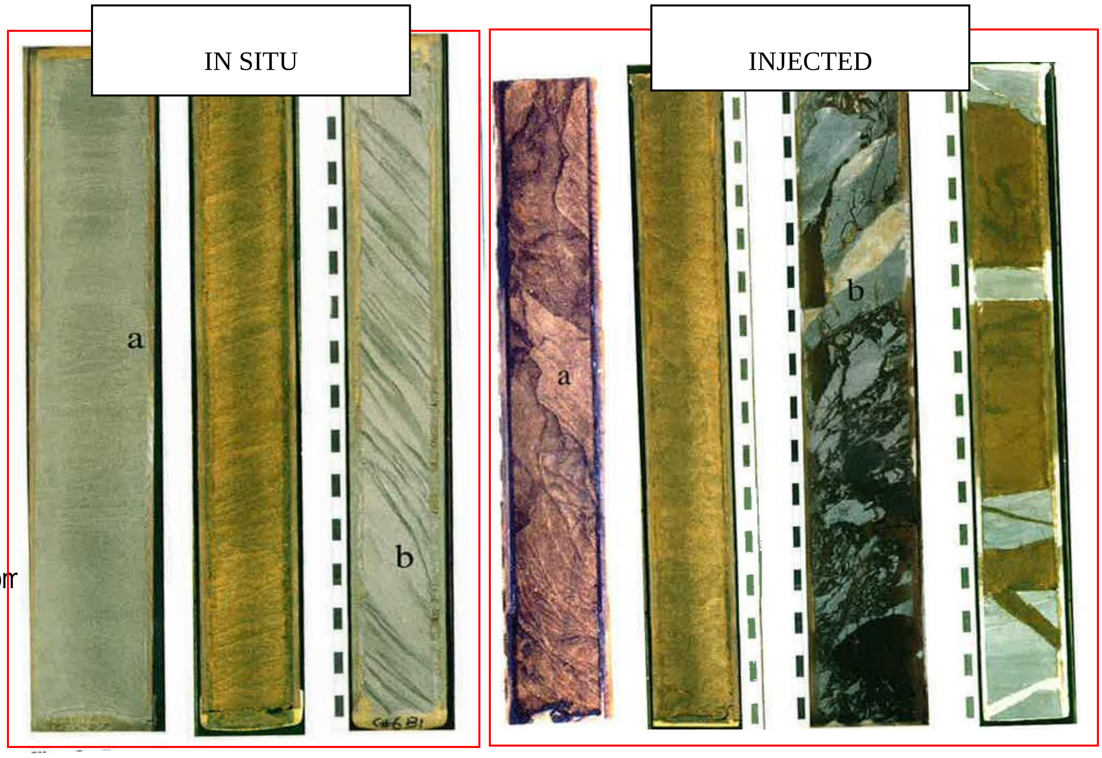
(Hurst & Cartwright, 2007)

Sandy turbidites, deposited from suspension, commonly display a loosely-packed grain fabric, whereas the flow of injected sands in the subsurface generates a more compact fabric with generally lower reservoir quality (Duranti & Hurst, 2004: *Sedimentology* **51**: 503-529). Distinguishing between turbidites and injectites is therefore key to predicting primary reservoir quality (before diagenetic overprinting). Observations from core are the most effective way to do this; image logs generally lack the resolution needed to identify diagnostic features.
Identifying and distinguishing turbidites and injectites from core observation is not straightforward. For example, sandy turbidites deposited from suspension commonly record fluid escape as the sediment/water suspension collapses and fluid elutriates. This process forms coarse-tail graded beds, consolidation laminae, dish structures and fluid-escape pipes, which are diagnostic characteristics of turbidites. Similar features are seen in cored oblique injectites (e.g. Volund), showing that injection can deform entrained sand and silt mixtures, forming stratification that records the transfer of fluid through the injectite. Whether these features record true suspension fall-out is a matter of some controversy (e.g. Hurst & Cronin, 2001: *JSR* **71**: 136-143).

The scale of investigation can hinder the differentiation of sands injected into intact host rocks from large clasts of host rock enclosed within a sand matrix (e.g. bank collapse deposits). Examples of such bank-collapse deposits are shown from core (Norwegian data) and outcrop (Hubbard *et al.,* 2007: *AAPG Mem.* **87**:199-207). The correct identification of bank collapse features in gravity-flow systems (as opposed to injectites) can have profound implications for depositional modelling. For example, they are common in the channel lobe transition zone in turbidite fans. This zone is a source of hybrid event beds (HEBs), which are commonly transferred down range and deposited on the fringes of depositional lobes where they form baffles to flow.

Petrographic characterization of injected and *in situ* sands, including XRF- and XRD-based chemical and mineralogical typing, can be used to link injected sands to their origin. In the Catcher discovery *in situ* Eocene Tay and Palaeocene Cromarty sands have been differentiated based on Ti/Zr ratios (quantified using XRF) and feldspar content (semi-quantified with XRD). The provenance of injectites in off-set wells has been traced using the same techniques. Whilst ditch cuttings can be used to characterize very thick (10m scale) units, this approach is best used for cored intervals, where discrete injected sands can be identified and sampled.

Injectites form an economically and volumetrically significant reservoir component, which is sometimes visible on seismic. They commonly form the uppermost part of a reservoir, hence their irregular geometries add uncertainty to the development of predictive reservoir models. This is particularly important when trying to exploit attic oil. Even late in a field's life cycle it can be valuable to identify and quantify injectites within reservoir sands. This is best achieved using core.



(modified from

4th May 2021
Session two: Structural Challenges

KEYNOTE: Cores and structures

Haakon Fossen
University of Bergen, Norway

Cores are of invaluable importance in many aspects of petroleum geoscience. This presentation focuses on the importance of core information for considering the presence and importance of deformation structures in reservoirs, how to successfully use that information together with other information, and how to account for them during field development.

Small-scale structures found in reservoir rocks are generally invisible on seismic data and difficult to map from wireline well data. Nevertheless, subseismic structures are present in any faulted reservoir, sometimes in very large quantities, and are often thought to have some influence on fluid flow and reservoir performance. However, exactly how and to what extent can be difficult to evaluate. Even if we know that small-scale structures are present, we need information about the types of structures, how they affect porosity and permeability, and their reservoir-scale effect on fluid flow.

Cores can help us get close to a satisfactory answer in this respect. For instance, cores can tell us where subseismic structures occur with respect to lithology and in relation to larger structures such as seismically resolvable faults and folds. Combining such core observations with established knowledge from field (outcrop) observations and experimental work may enable us to evaluate these structures and take their effect into consideration during field planning and production. Furthermore, the type of structure and their properties can be assessed from core material. A large variety of subseismic structures can occur in reservoirs: fault drag, fault smear, damage zones, shear and extension fractures, stylolites, and several types of deformation bands (compaction bands, shear-enhanced compaction bands, shear-dominated bands, cataclastic bands, disaggregation bands, and more). All of these have different geometric aspects and petrophysical properties, and therefore influence production and injection in different, and sometimes opposite, ways. Hence it is imperative to use cores to find out what kind of structures occur in any given reservoir.

Knowledge of structure type and their influence on fluid flow must be paired with information about their distribution, orientations, lateral and vertical extents, and connectivity. Cores offer limited information about these aspects, and there is an important scale gap between the size of seismically resolvable structures and those observable in cores. Detailed investigation of core material is essential, but full core value can only be obtained when interpretations are based on extensive and sound knowledge of how the subseismic structures occur together in the reservoir and how they relate to larger-scale structures. Key elements are displacement-length relations, connectivity, variability of their geometric and petrophysical properties, distribution with respect to lithological parameters, relation to bed dip or curvature, distance to seismically resolvable faults, timing of deformation relative to the burial and lithification history, and tectonic setting. A thorough understanding of these relations must be based on general knowledge from other fields, physical and numerical experiment and, in particular, detailed field (outcrop) studies.

Maximizing value of core in fracture analysis using insights from structural diagenesis

Laubach, S. E., Gale, J. F. W.
Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX 78758, USA.

Fracture analysis has been a challenging area of research in the earth sciences for more than 100 years. The value of core in fracture analysis has long been recognized. But fracture attributes and patterns are exceedingly difficult or impossible to measure adequately using wellbores (cores, image logs) owing to inherent sampling limitations imposed by finite wellbore area of investigation and the distributed character of fracture arrays. Data on fracture presence, density of occurrence, local porosity structure, and some aspects of size patterns are rarely abundant enough for representative statistics, and extrapolations of such observations to areas not sampled are hard to justify. A common case is no fracture data in the zone of interest.

Recent studies show, however, that the information content and value of core in fracture analysis can be markedly increased by appreciating that linked chemical-mechanical (structural diagenesis) processes play a larger role in fault and opening-mode fracture pattern development than has hitherto been appreciated. A chemical perspective helps solve challenges to understanding subsurface fractures, including how to infer fracture porosity and permeability from limited subsurface samples, how to determine if outcrop analogs are accurate guides to specific subsurface fractures, how to determine fracture timing and origins and which fracture models are correct from limited core observations, and how to use core that has not sampled fractures to contribute to fracture analysis.

We show examples of these applications from unconventional and fractured reservoirs. We explicitly and rigorously illustrate the value of core in commercial decision making with value-of-information analysis for core data use in producing fields.

Learn to lean: the use of core in the digital age

Quentin Fisher[1,2], Ana Reyna Flores[1], Pebble Arrambi Diaz[1]
1 - School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK
2 – Petriva Ltd., University of Leeds, Leeds, LS2 9JT, UK

Core has proved invaluable in predicting the behaviour of many conventional reservoirs particularly those in which storage and fluid flow is matrix-dominated. For example, integration of routine and special core analysis with wire-line log data allows the estimation of petroleum volumes and the rate that it can be produced. Analysing the sedimentology of core and the structural features that it contains has proved essential for building geological models for production forecasting and optimizing production strategies.

The need to cut core decreases as a play matures and attention moves towards reducing development costs; a process that has been referred to as learn to lean. Two good examples of where there is less need for taking core to aid reservoir characterisation in mature plays are the estimation of porosity-permeability relationships of the reservoir and fault seal analysis. In terms of the former, it is now possible to predict porosity-permeability relationships in mature plays by applying recently developed artificial intelligence (AI) techniques such as convolutional neural networks (CNNs) to the analysis of the microstructure of cuttings obtained while drilling (Figure 1). The resulting relationships can then be integrated with the results from wire-line log analysis to estimate likely flow rates in either new wells or legacy wells that have been abandoned as tight but many now be developed using modern drilling and completion methods. In terms of fault seal analysis, many mature basins have large databases of fault rock properties that were derived from the analysis of core. The type of fault rocks present generally do not vary significantly across a particular play and their key petrophysical properties often vary in a systematic manner depending upon their thermal maturity. It is therefore possible to extrapolate existing studies to new fields within that area without the need for further core analysis.

New plays do not, however, have sufficient core or core analysis results to establish regional relationships or to train CNNs. In such cases, it is still essential to cut core in the early stages of exploration and appraisal, which can then be used to provide the data and understanding to cut costs associated with field development. Even in new plays, it may be possible to reduce costs associated with reservoir characterization during exploration and early appraisal by carefully planning where core is taken. For example, purposefully collecting core from close to seismic-scale faults may mean that the knowledge gained on the type and flow properties of fault rocks is sufficient that less core is required during appraisal to conduct robust fault seal analysis throughout the production-life of the basin.

Applying AI techniques to the microstructural analysis of cuttings to predict reservoir properties in new plays requires relevant core to be taken and appropriate core analysis to be conducted. It also requires drilling is optimized in later wells to provide cuttings that are of sufficient quality (size) for them to provide a good representation of the microstructure of the reservoir as a whole. The best practise for obtaining useable drill cuttings still represents a significant knowledge gap as there is significant uncertainty regarding how the size of cuttings is influenced by rock properties, the type of drilling bit, weight on the bit, rotary speed and method, mud type etc.

In conclusion, the availability of core and core-analysis studies in mature plays means that there robust reservoir characterization can often be conducted without the need to cut new core particularly by applying recently developed AI techniques. Characterization of new plays will still probably require core to be taken during exploration and early appraisal. However, careful planning and the application of AI will allow this to be undertaken without the need to cut the large amounts of core that have been taken in the past.

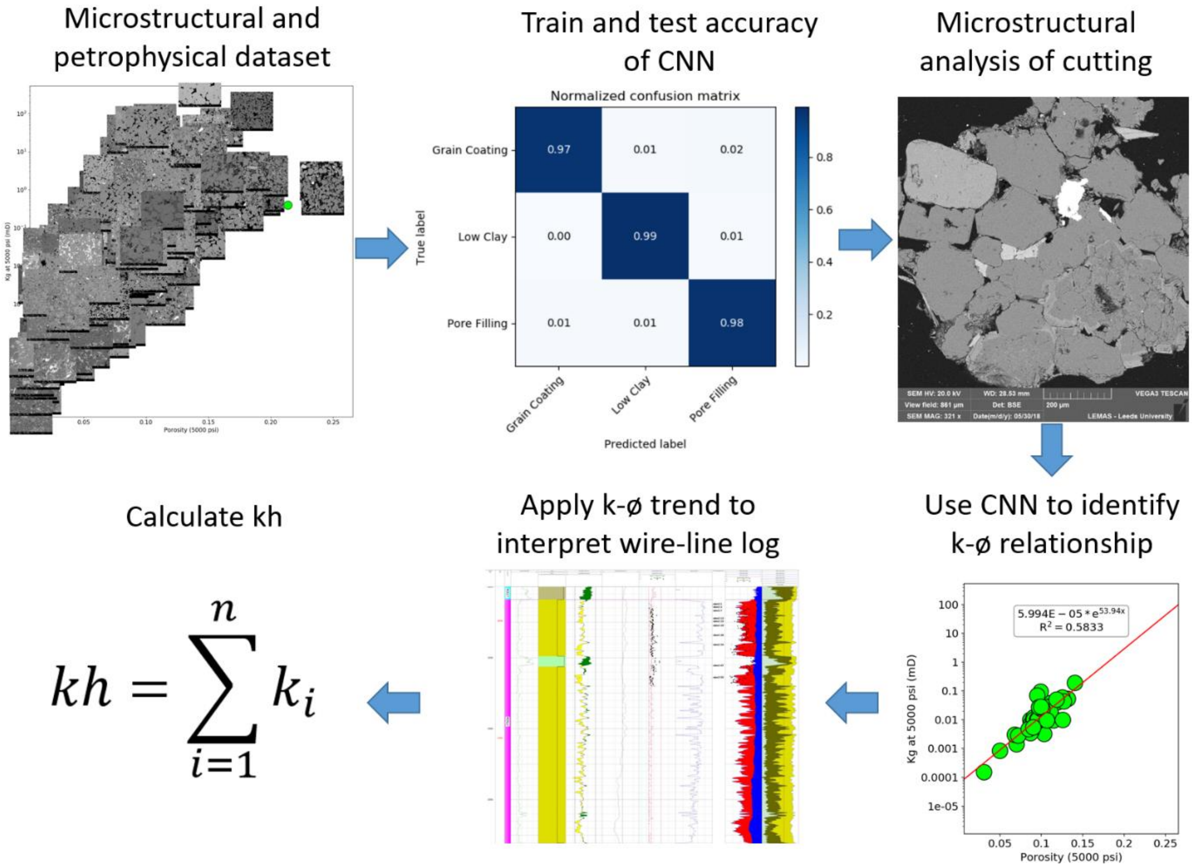


Figure 1. Workflow for predicting likely flow behaviour of reservoirs by cuttings analysis involves: (i) collecting robust datasets on the microstructure and petrophysical properties of core samples, (ii) training CNNs to relate microstructure to porosity-permeability relationships, and (iii) using the relationships to calculate kh values from wireline logs.

5^{th} May 2021
Session three: Core and Imaging

Multi-scale rock characterisation and data integration: a case study from the BGS Core Scanning Facility

Magret Damaschke[1], Simon Wylde[1], Mark Fellgett[1], Andrew Kingdon[1]

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Physical and chemical characterisation of sedimentary successions from core underpin a number of areas of geoscience, including source rock and reservoir evaluation, correlation, and, palaeoenvironmental analyses. Recent technical advances in the capabilities and analytical precision of X-ray florescence (XRF), computed tomography (CT), and multi-sensor (MSCLS) core scanners mean that they are increasingly applicable to such studies. In contrast to traditional semi-destructive sampling techniques, they offer the ability to rapidly acquire non-destructive and near-continuous records. These measurements can be integrated with other datasets at different scale, thereby increasing analytical resolution and the value of core material at the same time as reducing costs.

The new Core-Scanning Facility (CSF) at the headquarters of the British Geological Survey (BGS) in Keyworth houses four high-resolution core scanners – two XRF's, a CT, and a MSCLS – enabling geophysical, mineralogical, and geochemical characterisation of core and allowing high-definition optical, near-infrared (NIR), ultraviolet (UV), and X-radiographic images to be collected. The facility was commissioned to provide fundamental support to the NERC/UKRI funded UK Geo-Energy Observatories (UKGEOS; https://www.ukgeos.ac.uk/), an initiative to characterise the subsurface environment at 2 localities (Glasgow and Cheshire) in order to better understand the impact of subterranean infrastructure and the role rocks may play in decarbonising energy supplies.

Here, we use the preliminary results from the Glasgow Observatory as a case study to demonstrate how core scanner datasets are generated, evaluated, and visualised. This involves integrating core scanner outputs with other data generated at widely different scales (e.g. wireline logs, core plug analysis). We highlight the value of core scanning as a mechanism for correctly reconstructing the vertical position of core, for identifying specific intervals of interest, and for resolving new relationships between physical and chemical properties. The core scanner data can also highlight changes in the rock properties that would not be easily identified by conventional downhole geophysical logging and point geochemical sampling. Our ultimate goal is to generate a multi-scale "digital twin" for each core, freely available online, that will allow a more complete understanding of the variability of rock properties.

Hyperspectral Core Imaging for Oil & Gas applications

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Hyperspectral imaging is a relatively new technology for identifying and mapping mineralogy in drill cores and cuttings. It has been used by the mining industry for over 15 years, but in the oil and gas industry the technology has only been applied for the past 4-5 years. Hyperspectral core imaging involves moving core or cuttings samples below a set of hyperspectral cameras that collect infrared data, ranging from the short-wave infrared (SWIR) through the mid-wave infrared (MWIR) to the long-wave infrared (LWIR, together with the MWIR also called the thermal infrared).
Hyperspectral imaging is a non-destructive technique that is able to rapidly acquire information about a wide range of minerals, which includes silicates (and importantly direct speciation of clays), carbonates, sulfates, oxides and hydroxides. The term hyperspectral describes collection of many bands of spectral data (typically >100) and allows for mineral chemistry to be determined for many minerals; and in the LWIR range, for particle size determination of quartz and carbonates that facilitates mapping of cement.
Data processing involves the direct detection and mapping of minerals, and also the extraction of absorption depths and wavelengths of spectral features (in the SWIR and MWIR) and peak heights and wavelengths (in the LWIR) that provide information about relative abundance and composition of minerals. This information can be utilized to produce rock types to guide selection of plug locations for conventional and special core analysis.
To date, we have applied hyperspectral imaging to a variety of conventional and unconventional cores including carbonates, siliciclastics and evaporates to identify mineralogy and map the textural relationships of minerals. Hyperspectral data has been integrated with other data (such as core descriptions, petrophysical information, porosity, permeability, thin-section petrography, XRF, XRD, etc.) to aid in geological and petrophysical quantification and 'up-scaling' from thin-section/core plug scales to depositional system understandings. Although the spectral information is semi-quantitative, it can be correlated with XRD mineralogy to produce continuous single mineral curves down the hole.

Fully Integrated Borehole Image and Rotary Sidewall Core Data for Effective Near-Field Appraisal

Adrian Neal[1], David Storer[2], Tom Baird[2], Dave O'Gorman[2], Ross Hartley[2], Dorothy Payne[1] and Andrea James[1]

[1]Badley Ashton and Associates Ltd., Lincolnshire

[2]BP Aberdeen

Quad 29 of the Central North Sea is a focus area for BP with a strategy to identify remaining hydrocarbon accumulations to tieback to existing infrastructure. Capercaillie was appraised in 2017 with well 29/04e-5 and sidetrack 29/04e-5Z to evaluate deeper targets. A gas cap with a thin oil rim was intersected within the siliciclastic Sele Formation, which was deposited in a deep marine setting by sediment gravity flow processes. It is part of the same depositional system as Vorlich, a recent BP development in conjunction with partners Ithaca. With existing knowledge and experience from the field a similar development and tieback to surrounding hubs is being evaluated for Capercaillie.

The relative size of the field and ambition to appraise deeper intervals with a sidetrack required an optimised data acquisition programme designed to balance overall appraisal information, operational risk and costs. Given existing knowledge of the area it was felt Capercaillie could be appraised with a full wireline logging suite, pressures, high resolution image logs (BHI) and large volume rotary sidewall cores (RSWCs).

The latest high resolution oil-based borehole imaging tool now allow for significantly improved identification of lithological variations, sedimentary structures and depositional context, even in the absence of core calibration. This leads to increased confidence in descriptions and subsequent interpretations. In deposits dominated by sediment gravity flows, it is now common to be able to identify debris flows and hybrid beds, through imaging of their individual component clasts and surrounding mud-rich matrix. In the Sele Formation such deposits play a key role in understanding both its sedimentology and reservoir quality.

Proprietary deepwater descriptive schemes were applied to the Sele Formation at the RSWC (lithotype), bed (borehole image facies) and bed-stack (BHI depositional package) scales. This hierarchical approach provided robust sedimentological descriptions and related models, which were then used as a framework to: 1) constrain the reservoir's mineralogical and textural attributes, 2) establish the main controls on relative rock quality, 3) examine the resulting variations in porosity and permeability, and 4) identify key unresolved reservoir issues.

This presentation will demonstrate the power of a fully integrated study based on an optimised data acquisition programme. The reservoir development team within BP have been able to effectively describe the reservoir and identify the key risks and uncertainties associated with the field through;

- Acquiring the right data from the wells
- Having a common and robust descriptive framework applied across all datasets
- Targeting petrographic analyses based upon the sedimentological framework provided by the BHI
- Employing a dedicated reservoir characterisation team with skills across the full range of relevant disciplines (borehole imaging, sedimentology, petrography, reservoir quality).

An integrated study of core and FMI data; karst development and structural evolution of Late Permian siliceous carbonates, Gohta discovery, Loppa High, SW Barents Shelf

Joanna Garland, **Peter Gutteridge** (Cambridge Carbonates Ltd), Niels Rameil, Mike Charnock and Israel Polonio Martín (Lundin Energy Norway AS)

Core from 7120/1-3, the Gohta discovery well, on the Loppa High showed that the Lower Røye Formation (Lower Permian) had been extensively karsted during at least one episode of pre-Triassic exposure. Integrating the karst facies observed in the core with image and dip data seen in the FMI has allowed the Loppa High structure to be untilted. The karst system is preserved as interlayered cave floor, external fill, cave fill and collapse breccias with intervals of intact host dolomite and foundered beds of siliceous sediment. The karst system is interpreted as a series of collapsed and infilled thin, layer parallel caves. Open caves are preserved as collapse breccias, whereas caves filled by sediment were prevented from collapse and contain well-preserved layered sediments as well as occasional stalactites, stalagmites and cave floor structures such as boneyards and sub-cave cavities formed by dissolution of the host dolomite. Stalactites can also be used as geopetal indicators in the core. An early karst infill comprises laminated fine doloarenite with a matrix of greenish clay interpreted as an internal matrix generated by cave collapse. A later karst infilled comprises laminated dark grey argillaceous mudstone interpreted as an external fill derived from the overlying Triassic.

The core therefore provides information about the origin and significance of the varied karst fills and their dip character together with sequential information about their timing of deposition. The karst components observed in core were then matched to the image character of the FMI log and their dip azimuth and inclination can be fully specified. The dip of the overlying Triassic Klappmyss Formation that buries the karst system can also be specified using the FMI dip data. This allows the structural history and timing of karst development of the Gohta structure to be determined as follows:

1. *In situ* stalagmites and stalactites represent poles to a palaeohorizonal surface
2. Plunge of stalactites and stalagmites sit within the distribution of poles to bedding in the host Røye Formation suggesting that the karst was initiated while the Røye Formation was slightly tilted to SE.
3. There was progressive incremental tilt of the Gohta structure to the SE during deposition of the doloarenite and argillaceous mudstone karst matrix.
4. Dip of subsequent karst components indicate phases of incremental tilting
5. There appears to have been a reversal of tilt of the Gohta structure prior to deposition of the Klappmyss Formation, although there is likely to have been some modification of the dip by differential compaction.

Comparing advantages of RSWC and whole core in a West of Shetland exploration well

***Emma Jude*[1]*, Valerie Goggin[2], Richard Dixon[1]*
[1]BP Exploration, Sunbury [2]BP Exploration, Aberdeen

The Achmelvich well is located in Licence P2125 which is located to the SE of the giant Clair field, West of Shetlands. The well drilled a Cretaceous prospect, targeting deepwater turbiditic reservoirs which onlapped the Shetland Platform. The well also penetrated the underlying Devonian fluvial sands in search of deeper secondary prospectivity. A total of 96 rotary sidewall cores and a high-quality QuantaGeo™ image log were obtained through both intervals.
The deeper Devonian reservoirs were broadly as anticipated and were correlatable with the Clair Group reservoir units on the Clair field. However the Cretaceous interval was significantly different to prognosis. The penetrated reservoirs comprised highly variable conglomeratic facies dominated by pebble or larger grain size. These data necessitated a re-assessment of the pre-drill deepwater depositional model, resulting in the reinterpretation of the Cretaceous section as a subaerial/subaqueous short-runoff alluvial fan-delta system of limited extent, derived from the Shetland Platform.
In this talk, we compare and contrast the value of RSWC/QuantaGeo with core in the two intervals.
Firstly, we consider the well understood and extensive Devonian fluvial system in the Clair field, and integrate with the Achmelvich data. The RSWC/QuantaGeo can here be considered an advantage over conventional core, as additional information such as palaeocurrent data can be easily obtained. Given the relatively homogeneous nature of the Devonian system, the RSWC database was representative enough to integrate with heavy mineral stratigraphy and reservoir quality studies to compare with the neighbouring Clair field.
Secondly, we propose that while the RSWC/QuantaGeo dataset allowed us to construct an alternative depositional model for the Cretaceous, it was not sufficient to fully characterise the poorly calibrated and highly variable Cretaceous system. Key barriers to the interpretation include facies incompletely sampled or missed by RSWC, features below the resolution of the image log, lack of identification of conglomeratic clasts, and insufficient data on observed high permeability thin beds.
Finally, we will illustrate the workflow used to mitigate this and propose alternative depositional models for the Cretaceous section. Sidewall cores were integrated with petrographic data and a scale interpretation of the image log to produce a ‘pseudo-core description’, borrowing from the principles of core description to identify significant surfaces and sedimentary structures at a greater level of detail than conventional image log facies interpretation. The result was the identification of changes in sedimentary style which allowed us to reconcile the whole dataset to a consistent depositional model.

5^{th} May 2021
Session four: Unconventionals

KEYNOTE: Core Characterization of Unconventional Reservoirs: Impact into play de-risking and development decisions

Patricio Desjardins. Shell Exploration and Production Company, Unconventionals

Unconventional resources have become a rapidly growing portion of the upstream business of IOCs. Its attractiveness resides in the profitability of large discovered reserves and the ability to control development pace which can be used to balance reserves replacement and production curves. Geologic understanding plays a crucial role during the de-risking and development phases of unconventional resources by providing a framework for data integration. Robust geologic understanding enables high quality decisions which greatly impact the value of a project. Proper delineation of "best areas" within a large "continuous" reservoir (tens of thousands of Km^2) is one of the critical success factors. Others are related to de-risking and development decisions, such as where in the stratigraphy to land wells, size of target windows, and number of wells per drilling spacing unit.

A trial & error approach to develop "gigantic and homogenous" unconventional reservoirs has proven to be a terrible idea and had led to the erosion of capital within our industry. This experience called to the need of better characterization, understanding and predictability of unconventional reservoirs.

In this keynote I will share case studies and summarize learnings of how core characterization of unconventional reservoirs impact business decisions. Focus areas will include: 1) Maximization of cores from consortiums, data trades and publically available data to built robust stratigraphic and sedimentary frameworks for integration; 2) What formation characteristics impact access to hydrocarbons through hydraulic fracturing; 3) Well landing target and well spacing decisions; and 4) Technologies that aid the characterization of fine-grained reservoirs.

Examples to be shared include cores from Argentina (Vaca Muerta) and the USA (Permian, SCOOP-STACK & Eagle Ford).

The critical role of core in understanding hydraulic fracturing

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Improved understanding of hydraulic fracture growth and interaction with existing geologic discontinuities is needed to optimize drilling and completions strategies. It is well established that geologic discontinuities including natural fractures can be reactivated during hydraulic fracture treatments even when sealed with mineral cements. Other geologic features also affect hydraulic fracture growth. For example, the mechanical properties and stacking pattern of layers in a sequence may affect height growth. Mechanical properties of the layers also partly control their state of stress, and the ease with which they fracture during stimulation. Yet direct observations of the effects of these geologic features on hydraulic fractures are rarely made. Rather, operators tend to rely on indirect observation of hydraulic fracture growth through tracking of microseismic activity, and modeling of stimulation and reactivation processes (both numerical and analog). While these techniques provide many useful insights, we lack information to verify the results of such studies. The need for direct observation is high and is best achieved by taking core through intervals that have been hydraulically fractured, where the fracture fluid and proppant have been clearly marked.

We show examples from the Hydraulic Fracture Test Site (HFTS1) in the Permian Basin in West Texas to illustrate the value of core in understanding hydraulic fracturing. In this study, 600 ft of core was recovered from a slant well adjacent to two stimulated wells. The core revealed hydraulic fractures, natural fractures, and various drilling and core-handling fractures. Proppant packs were also observed. Notably, although image logs were taken in the cored well and in the two stimulated wells, these were of poor quality and under-recorded all types of fracture. A higher quality image log using a different tool, taken in another well on a nearby pad, more closely matched observations in the core. The choice of image log tool in the project wells was made according to valid engineering considerations, but led to inferior data. Without core there would have been no way to calibrate the image logs.

Core observations in the HFTS1 project were used either to verify or provide input data for models of hydraulic-fracture growth and proppant distribution. Reflection seismic data and results from microseismic monitoring were used to select the optimal sections of the well for coring. These techniques have coarser scales of resolution than can be obtained from core. Rather than regarding these visualization methods as alternative to coring, we make the case that they can provide complementary information. The core is effectively a line sample through the reservoir volume, but affords millimeter scale resolution of features. Seismic and microseismic data sets cover the reservoir volume, but with resolution of a few meters or tens of meters.

6th May 2021
Session five: Legacy Archives

KEYNOTE: The BGS National Geological Repository: making the most of core and samples

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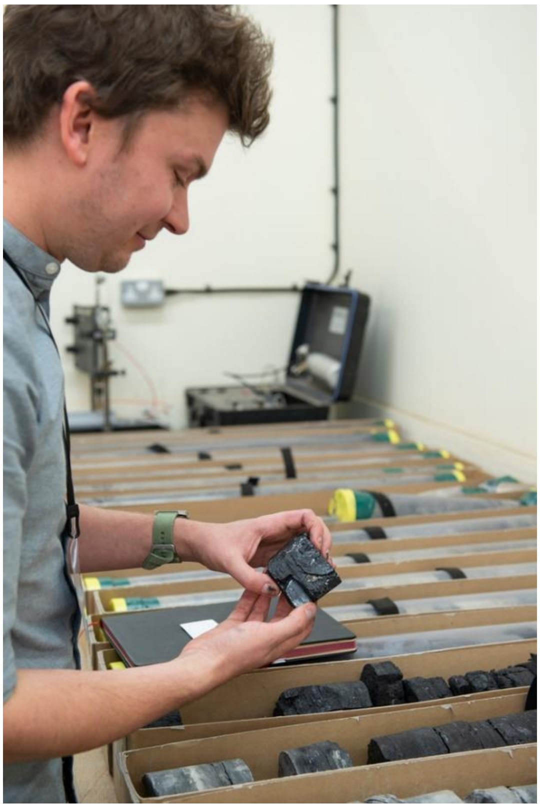
In Britain and the UKCS, it is a regulatory requirement under the Energy Act 2016 (and under PON9 & PON9b) that operators send at least a quarter cut of any core from exploration wells, and a half cut of any core from development wells, to the National Geological Repository (NGR) at the British Geological Survey (BGS), Keyworth, Nottingham, within 6 months from the completion of the wellbore. In addition, they are also required to supply a full set (minimum 100g each sample) of washed and dried cuttings.

The *Reporting and disclosure of Information and Samples Guidance*, provided under the Oil and Gas Authority (Offshore Petroleum) (Retention of Information and Samples) Regulations 2018, issued under section 34 of the Energy Act 2016, contains additional sample types that must be included in an Information and Samples plan (ISP) or notified should disposal be under consideration. These include unwashed samples, sidewall cores, geochemical samples, micropalaeontological and palynological slides and preparations, thin and polished petrographic sections, and grain mounts. Many of these additional samples will also be requested for the NGR. The NGR represents the physical samples archive of the OGA National Data Repository (NDR).

Mobile pallet racking in the UKCS core hall in the NGR, Keyworth.

After 185 of accessioning by the BGS, the NGR is now the largest collection of British geoscience samples, with approximately 16 million “specimens”, including over 600 km of drillcore from more than 22,500 wells and boreholes, held in three large storage halls and numerous associated facilities. Most of these samples are available for study and controlled subsampling by commercial organisations, academics and *bona fide* researchers. It is an access condition that copies of any resulting data, reports and publications are lodged with the NGR, and any preparations (e.g. thin sections, polished mounts, micropalaeo preparations) are returned. Raw data is made available after 2 years, and reports after 5, and are generally downloadable from the BGS website. A system of barcoded tickets links the sampling positions to the resulting data.



A researcher studying core in one of the NGR examination laboratories

The NGR has been at the forefront of international efforts to utilise digitisation and the www to improve collections impact. GIS access was provided to the onshore borehole collection in 2000, and GIS and text searching the other collections was added over the next 10 years. This was followed by high resolution images of the UKCS cores (e.g.: http://www.largeimages.bgs.ac.uk/iip/index.html?id=20120704/S00050923), petrological thin sections (e.g. http://www.largeimages.bgs.ac.uk/iip/britrocks.html?id=250000/258489) and high resolution images, stereo anaglyphs and 2000 3d digital models of British type fossils (see http://www.3d-fossils.ac.uk/) . The laser and structured light scanners for capturing 3d morphology have been followed by a suite of four core scanners: two X-ray florescence (XRF), one computed tomography (CT), and one multi-sensor (MSCLS) scanner.

It is a fundament principle of the scientific method that any published results should be repeatable. This requires the archiving of sufficient samples to support published observations and conclusions. This is also a requirement of the ISO 9001:2008 Quality Management methodology. Re-purposing archived information and samples for new research saves money and time and thereby reduces risk. It is estimated that the NGR archive has cost over £200b to collect and the cost of a single deep cored borehole would be outside the funding of most research projects, so the operation of a NGR makes excellent financial sense. Also, the fact that many of the wells and boreholes have been extensively characterised means that new research can build on the wealth of published data, rather than starting from scratch.

Multi-Parameter Scanning of Archive Core as the Backbone of the Digital Repository

James William Shreeve, Geotek Limited
Briony Shreeve, Geotek Limited
Melanie Holland, Geotek Limited

A core repository is a physical record of a country's or commercial organisation's subsurface wealth, as well as an academic source for countless research programs. Some of the largest core repositories hold 1000s of km of core material and it is challenging to find a solution to turn this physical archive into an accessible digital resource for all. Non-destructive multi-sensor core logger (MSCL), hyperspectral and X-ray imaging techniques offer a unique chance to rescue valuable data trapped within core samples that have never been recorded before. However, these technologies output enormous quantities of data that require organisation and, more importantly, visualisation. Here we present a case study of an archived petroleum core acquired in 1985 at the Osprey Field, UKCS. Original downhole data, lab test reports, visual descriptions and core photographs are augmented by a high-resolution core scanning dataset that is downloaded into a cloud-based digital repository. Advances in cloud-computing offer a unique opportunity for core repositories to benefit from unlimited storage and computing power that would otherwise be unaffordable or even unattainable. The Osprey Field dataset shows how core scanning can unlock an abundance of new data from core that is 35 years old, slabbed, and heavily sampled. The legacy and new data together create a digital collection made accessible through database and visualisation software to enable commercial or public users to virtually interrogate the archive, visualise the core and its properties, identify useful stratigraphy, and intelligently select samples for destructive testing. A workflow (Figure 1) is established to optimise the use of legacy cores and exploit the abundance of data trapped within the core repository through the use of multi-parameter continuous core scanning and imaging data which are stored within virtual environment for visualisation and access to all.

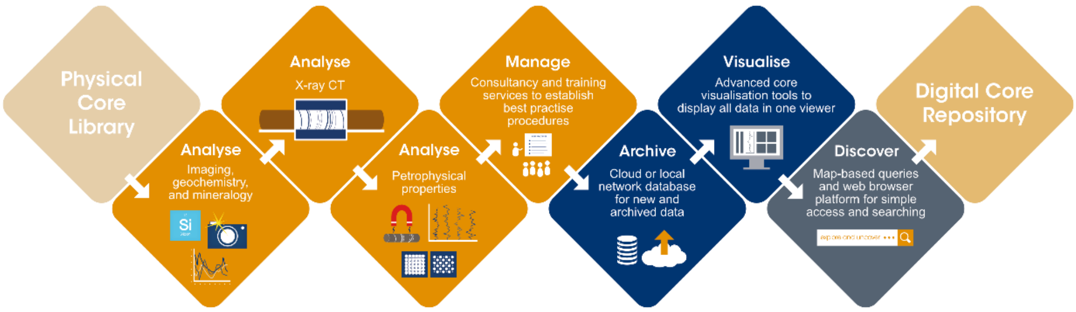


Figure 1: A proposed workflow using multi-parameter core scanning techniques combined with database and visualisation software to unlock the data trapped within the core repository.

The Second and Not So Secret Life of Core with the North Sea Core Initiative

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North Sea Core CIC is a volunteer-based initiative, set up in response to the release of core material through the relinquishment, abandonment and decommissioning of fields along the UK Continental Shelf. The initiative started in October 2017, officially launching in November 2018 and becoming at Community Interest Company (CIC) in May 2020. Founded on the basis that core material provides an incredible resource for understanding the subsurface, the aim of the initiative is to collect and distribute core to the wider geological community.

At the time of writing, core material has been donated by seven companies, from across the UK Continental Shelf although the North Sea dominates. Ages range from the Carboniferous to the Paleocene and are documented though samples of both cut and biscuit core.

The range of materials we provide includes educational and research supplies, individual core samples and framed displays, workshops and bespoke teaching sets. To date we have supplied >300 national and international requests to >20 countries, with core delivered to >30 universities and research centres. We are also fortunate to have had our Exploration Boxes, which focus on variety geological aspects of the North Sea, sponsored by the Oil and Gas Authority, the Petroleum Exploration Society of Great Britain and the Petroleum Group of the Geological Society (now the Energy Group)

The variety, scale and nature of the requests we receive clearly indicate that the value of core should never be underestimated. Long after the material has been seen to serve its purpose within the exploration sphere, core has the potential to answer new questions. It can have a second life in the education of the next generation of geoscientists, help make geology accessible to non-scientists, and aid in research for present and future energy needs. In this talk, we aim to present how we have successfully been able to facilitate the collection, transformation and distribution of core material and demonstrate the impact it has had.

USGS Core Research Center: A gateway to subterranean discovery for geoscience research

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The U.S. Geological Survey (USGS) operates a repository that provides public access to a vast collection of scientifically valuable rock cores and drill cuttings. Since its establishment in 1974, the USGS Core Research Center (CRC), located in Denver, Colorado, USA has amassed a collection of rock cores from more than 9,700 wells, and cuttings from more than 52,000 wells.

The CRC's collection of core and cuttings were collected from 33 states, with most of the materials having originated in the Rocky Mountain region and adjacent states. Annually, about 1,400 domestic and international researchers representing industry, academia, the USGS, and other government agencies use the climate-controlled examination rooms at the CRC to assess potential energy and mineral reserves, gather data for theses and dissertations, and conduct and verify resource assessments.

Innovations in petroleum extraction technology have enabled previously unproductive geologic formations to yield vast amounts of oil and gas, returning the U.S. to rank as a major supplier of petroleum products. Traditional geologic knowledge, derived from the physical rock materials housed at the CRC, paired with new extraction methods, have unlocked numerous productive deposits. Although most frequently used for oil and gas exploration, the CRC collections are also used for evaluating water resources, mineral resources, isotopic analyses for paleoclimate studies, and other innovative research.

The CRC website offers the ability to search the collection database via a text-based or map-based interface. Core photos, analytical data, and thin section images are available for download from the website. CRC policies balance the needs of today with the needs of the future by allowing visiting researchers to receive samples for limited destructive analysis with the requirement that the analytical results will be returned to the CRC and shared publicly. A minimum representative quantity of every depth is preserved in perpetuity. The CRC maintains 18,000 files of analyses and 29,000 thin sections that were submitted by users from the sampled materials. Sharing these results provides immediate, free access to users and spares the finite and largely irreplaceable collection from redundant testing.

Customer behavior documents the importance of the collection. Although the CRC does not charge for usage, all visitors incur the costs of travel. Annually, CRC visitors collect about 3,000 samples, pay for all laboratory fees for their chosen sample analyses and then share the raw data. During industry downturns researchers use the collections for a low-cost method to reach important decisions even while money is scarce, and mistakes could be devastating.

With a long track record of service to the cyclical oil and gas industry the CRC curators have learned that the importance of formations and areas will cycle in-out and possibly return to favor as new techniques are discovered. Conserving today's ignored materials may be crucial to meeting the needs of unforeseen future research. Materials drilled and curated decades ago are still in high demand by current researchers.

The collection provides immediate inexpensive access to the actual subterranean materials at a miniscule fraction of the cost of drilling, sparing money, time and environmental impacts.

Automated Image Analysis – assessment of core quality from legacy data

Mark Fellgett[1], Saswata Hier-Majumder[2], Andrew Kingdon[1], Simon Harris[1] Corresponding Author: Mark Fellgett, [1]British Geological Survey [2]Deptment of Earth Sciences, Royal Holloway University of London

Today's energy challenges often require geologists from operators and/or regulators to revisit legacy core to use as analogues for new sites or new processes, for example subsurface storage. Compared with the cost of drilling boreholes to acquire new core, the cost of new analysis on these cores is small. Technological developments also allow for the collection of more and more data without destructing the core material. This changes a financial liability to a research asset.

Scanning technology allows collection of consistent measurements of properties from core such as X-Ray Fluorescence (XRF), Magnetic Susceptibility and P-wave Velocity. This presents users with the opportunity to collect vast amounts of data from multiple boreholes which can then be upscaled into reservoir models without the need to break ground.

However two cores, even taken from the same stratigraphic unit are seldom the same and changes in diameter, drilling method, storage conditions, lithology and handling can all drastically impact their degradation during acquisition and storage. To ensure consistency of outputs from core scanning requires a method of assessing the condition of legacy core. This could also be used to assess uncertainty in core scanner data. These are key challenges for the new Core Scanning Facility (CSF) at the British Geological Survey (BGS) at Keyworth.

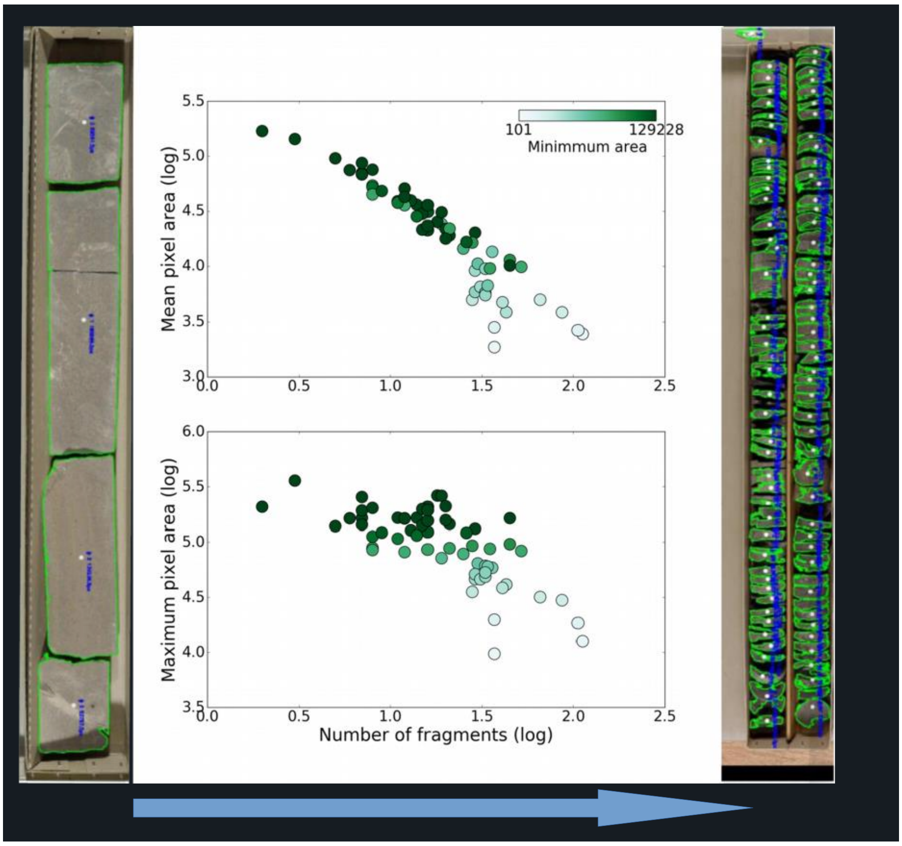
The CSF is co-located with the National Geological Repository which hosts over 200 kilometres of core from the UK Continental Shelf (UKCS) alone. This presents the opportunity to develop new data analyses for legacy core to serve and enhance the requirements of regulators, researchers and operators. Efficient operation of the facility and consistency of outputs therefore requires new information on core quality to maximise its value. This will also aid researchers seeking suitable material in stratigraphic units to sample more effectively. This will reduce time and effort spent examining material too degraded to allow for collection of the coherent samples, which are needed for many laboratory tests.

An existing data asset which can be used to directly assess core quality is the BGS archive of optical visible light photographs (https://www.bgs.ac.uk/data/offshoreWells/pgc8.html) of UKCS core. This contains a very large database of over 125,000 images of core condition at the time this material arrived at NGR, with more data being acquired on a monthly basis. Consequently automation is the only realistic way of efficiently extracting additional value from this resource.

To investigate whether an automated solution could be used to assess core quality a machine learning approach was undertaken. This used pre-trained neural networks on an initial training dataset of 62 images. The approach fist segmented and then analysed each image to classify the number of core fragments in each image, including the surface area of each fragment.

Results from this study show that analytical outputs from image analyses may be used to describe and index core condition. The outputs include simple metrics which can be presented alongside complimentary datasets such as core scanning or core plug analysis. When combined with the extant (large) databases of UKCS core depths and pre-existing stratigraphic interpretations of the core this information can be used for identifying the best material for specific sampling activities. Some core scanning techniques, such as XRF, require a completely flat surface to collect reliable data. Careful assessment of core condition prior to its extraction from the archive is essential to improve efficiency both for operators of the scanners, and the clients.

This will allow any researchers working on field scale studies the chance not just to process large volumes of optical images but to give an idea of variation in core quality between wells. Such variations may also be used to target intervals to improve sampling success rates. These techniques are being further analysed to understand if they may also allow be used to directly assess physical properties of core parameters.


101
129228
Minimmum area
Mean pixel area (log)
Maximum pixel area (log)
Number of fragments (log)

6^{th} May 2021
Session six: Modelling

KEYNOTE: Cores as an integrated part of the reservoir modelling workflow to reduce uncertainty and to build rigorous 3D models

Nordine Sabaou, BHP, Houston, USA

Reservoir modelling is necessary to assess the commerciality of a new discovery or a discovery under appraisal, establish a field development plan, or optimize a field already on production. The reservoir model is an attempt to accurately portray a complex, heterogeneous reservoir system using a suite of various data. The main goal is to create robust models with geobody geometries and flow properties consistent with available data.

Acquiring core data demonstrates the tremendous value to contribute towards stratigraphy, petrophysics, and even seismic interpretation in order to provide a quantitative, integrated and robust reservoir model ready for field development planning, simulation and production history matching. Cores build the foundation to understand the reservoir heterogeneity and distribution of facies extending away from known well control, capturing the best geological continuity. This integrated approach creates significant value and reduces uncertainties by using multiple geoscience data types. A fully representative geomodel can be very challenging to achieve even if the data is abundant and of good quality.

The classic reservoir modelling workflow follows steps of integrating core data, stratigraphy, petrophysics, and seismic interpretation into a subsurface reservoir model. Identifying lithofacies from core, which can be upscaled to electrofacies using calibration with wireline logs, is a must have for a robust 3D geocellular model build. Cores and petrography, logs and seismic facies, if available, need to be calibrated and correlated to each other in an integrated model.

The challenge of incorporating core description into a model is that the cores are described on a decimeter scale to capture the fine-scale heterogeneity whereas the model cell size is generally 100mx100mx1m. The reservoir modeler has to find a way to capture the heterogeneity as accurate as possible. Even with this rigorous approach, the lithofacies and any related reservoir property will end up averaged in a grid cell.

For example, seismic inversion, which is a tool that predicts reservoir facies and properties away from calibrated well control, may help to support the loss of details when upscaling cores to model, even with a resolution of several meters. However, the inversion will only be successful if the distribution of porosity and permeability comes from a reliable source. Petrophysical data obtained from core plug measurements are normally considered to be more accurate and are used to calibrate log data. Existing core poroperm data will be used for populating a 3D geocellular model.

If core data is limited, only a rough estimate of key reservoir property parameters can be made and needs to be supported by the log data. This circumstance is not ideal, but the geomodeler has to maximise the use of all data by making subjective modelling decisions and develop a workflow that identifies key uncertainties, defines the range of properties, and uses of geological concepts and appropriate analogues.

It is proposed that reservoir modelling and simulation tools should be employed to understand the upside and the downside. Use modelling to quantify upsides and downsides rather than fine polish a best guess which is unlikely to be correct *(Bentley 2015).* Dynamic data (production data, well tests, pressure, etc.) synthetized by reservoir engineers is critical to validate the geomodel and enables high grading of areas for efficient field development and production.

Most decision-making processes in E&P are based on models, which are representations of the reality, not on the reality itself *(Meunier et al., 2013).*

Core data provide excellent, but finite, deterministic control on the stratigraphic and depositional frameworks (*Cox et al., 2013*). Away from well control, the depositional framework can be poorly resolved by seismic data, and meaningful extrapolation into the inter-well areas remains challenging. Integration matters and is essential when constraining uncertainty in the subsurface and when taking key decisions.

The key uncertainties in a reservoir model generally are, the distribution and connectivity of the reservoirs away from well control as well as permeabilities that characterize flow units, and hydrocarbon saturations. Geostatistical processes have to be applied to integrate all the data from core to seismic and produce multiple realizations to quantify uncertainty. Often, reservoir engineers utilize property multipliers during simulation of a geomodel in effort to understand uncertainty.

High quality geomodels should capture the spatial distribution of the reservoir net sand and pay, and should be consistent with available data and geological concepts. This results in better defined uncertainty in the Hydrocarbon-in-place volumes. Ultimately these models will lead to better history matching and more reliable predictions in dynamic modelling for optimum field development planning, thanks in part to the availability of core data in the first place.

Characterising small scale heterogeneities during core analysis increases the predictability of field scale flow models of CO_2 storage

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Department of Earth Science & Engineering, Imperial College London

The accuracy of predictions of injected CO_2 migration and trapping are sensitive to multiphase flow properties – the relative permeability, capillary pressure, and residual trapping characteristics *[Krevor et al., 2015]* – and the lab-to-field upscaling process used to incorporate these properties into numerical simulations of fluid flow.

There are a number of well known examples of industrial scale storage projects where CO_2 has migrated rapidly in directions that have not been accurately modeled using plausible uncertainty envelopes for considered reservoir properties *[Singh et al., 2010]*. Examples include the Equinor led Sleipner project in Norway and the BP led In Salah project in Algeria. It is possible that the upscaled impacts of multiphase flow heterogeneity represent a key component of the physics missing from these models.

Having observed the impact in the lab, we have evaluated the upscaled impact of these centimeter-to-meter scale heterogeneities for a case study site – the Goldeneye field of the Captain Sandstone in the UK North Sea. We found that small heterogeneities can have first order impacts on plume migration at field scales, and manifest as flow rate dependent and anisotropic multiphase flow properties *[Krevor et al., 2011; Reynolds and Krevor, 2015; Reynolds et al., 2018; Jackson et al., 2018, 2019]*. For example, flow is accelerated in the direction of layering whereas trapping is enhanced in flow transverse to layers. We have since developed a tractable approach to measuring and incorporating these heterogeneities into numerical simulation workflows to increase the predictive power of plume migration models *[Jackson et al., 2018, 2019; Zahasky et al., 2019].* In a shift from current practice, the technique uses laboratory observations to calibrate numerical models of the rock samples obtained from the reservoir (Figure 1). The calibration can be based on imaged flow experiments *[Jackson et al., 2018, 2019]* or from numerical simulations on X-ray images of the rocks that resolve the pore structure, i.e., a digital rocks approach *[Zahasky et al., 2019]*. The models are in turn used to estimate flow properties at reservoir conditions. They are a first step in an upscaling workflow that honors the impacts of small scale heterogeneity on reservoir scale fluid migration and trapping.

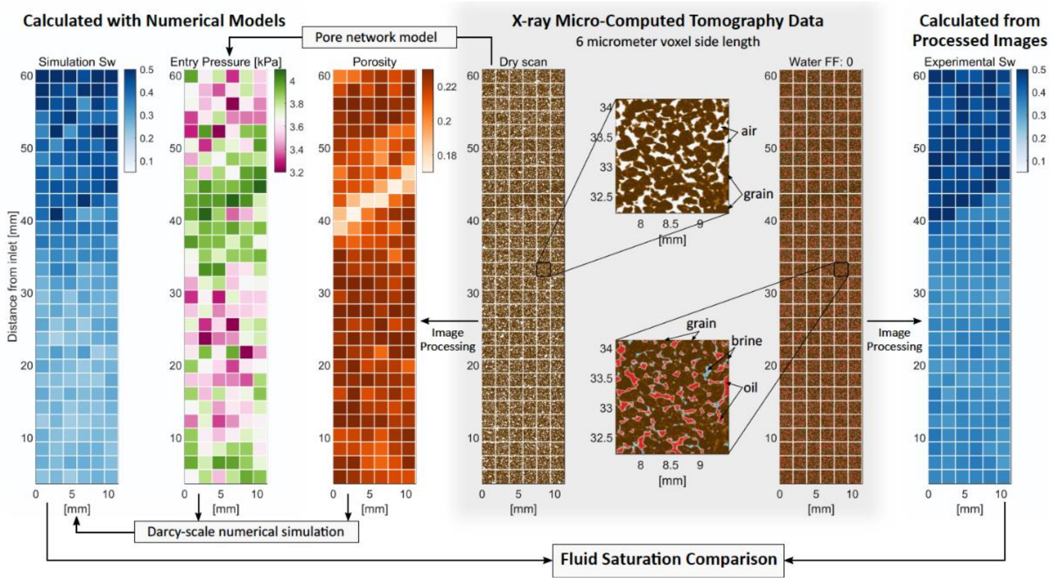


Figure 1. Validation of a digital approach to estimate heterogeneity in capillary pressure characteristics in a sandstone rock. From centre to left: X-ray images of the rock are used to generate a numerical pore network model representation of the pore space. This allows for an estimate of heterogeneity in the capillary pressure characteristics (entry pressure) which in turn is used to simulate fluid flow through the rock. Predicted fluid saturation (left) is matches well against independent experimental observations of fluid saturation in the rock (right) at the simulated conditions. From *Zahasky et al., 2019.*

7th May 2021
Session seven: The Future/Business

KEYNOTE: Not 'just a pretty rock': using core to reduce risk and deliver value in carbonate reservoirs

Anna Matthews
BP

Understanding and predicting the behaviour of carbonate reservoirs is often challenging throughout the value chain of exploration, appraisal and development. This talk will consider one of the major complexities of carbonate reservoirs, heterogeneity, and how core can help us unravel some of the complications. The prediction of reservoir quality, in particular permeability and its distribution, is vital for framing depletion planning in reservoirs of all types, but the uncertainties in carbonates can be greater than many clastic formations. Heterogeneity is commonly a significant challenge in carbonate reservoirs and workflows that deliver value will benefit greatly from calibration of core data to wireline logs, seismic and/or larger volume test data to predict likely reservoir behaviour.

Complex heterogeneity is seen in carbonates from the micro- to the macro-scale in any given field/reservoir, with the influence and significance of the different challenges varying throughout field-life. During exploration and appraisal, appropriate geological description of the core to establish depositional reservoir environment, architecture, distribution and large-scale flow zones may be the focus. Core material can help the petrophysicist to establish key reservoir parameters such as saturation, net-to-gross and wettability, with the petroleum systems analysts characterising the reservoir fluids. In turn, these inputs can significantly aid the geophysicists and geologists in their interpretation of seismic data. As development continues, there may be 'reservoir surprises' and the detail of the micro-scale, faults and fractures, diagenesis, particularly where not related to depositional stratigraphy, and thin high or low permeability zones may become more important. In carbonates this often requires core material to significantly reduce risk. The continuous integration of core and surveillance data e.g. injection and production logging tool (ILT/PLT) monitoring and saturation logs, can improve the robustness of models and help de-risk the development. Moving a reservoir from natural depletion into waterflood or to enhanced oil recovery may bring further challenges and require even more detailed and cutting-edge analysis techniques to deliver maximum value from the reservoir.

The role of the sub-surface team is to reduce risks and uncertainty around profile delivery, enabling reservoir management and investment decisions to be made. This is best achieved when core is available as it provides our only opportunity to make direct measurements on the reservoir rock. Many and varied techniques are available to the team, but with limited material and budget, effective planning of core studies is crucial to delivering the information needed to make the most appropriate decisions throughout field life.

Use of machine learning for automation of core identification for robust reservoir characterization and prediction

Author: Kumar Satyam Das-Presenter (Shell Netherlands, Assen), Kumar Sundaram Das (Petrotel-Dallas)

The present paper describes the use of core along with automation of core-facies identification. The concept of facies modelling is often applied in the construction of reservoir models for hydrocarbon accumulations. A facies *model* consists of a number of different facies that together describe the lithological variability in a certain depositional setting. The three-dimensional distribution of facies bodies follows certain geological rules. Thus, a suitable facies model, in combination with a good understanding of the geological rules, gives important clues for the three-dimensional distribution of flow properties in a reservoir. Facies models are compiled by geologists on the basis of observations and interpretations from core material. Usually, core material is available from a limited number of wells only, and the interpretation in terms of facies may differ between geologists. This hampers the construction of accurate reservoir models. The current study aims to develop an Artificial Intelligence (AI)-based approach to allow accurate identification of facies from conventional wireline log responses, which are available for almost every well.

Objectives

The key objective of the current study is to construct supervised predictive models to enable automation core identification and reservoir facies identification in Rotliegend wells that have not been cored. This should lead to increased consistency and decreased throughput time of facies interpretations, hence to more accurate reservoir models and better investment decisions in a shorter timeframe.

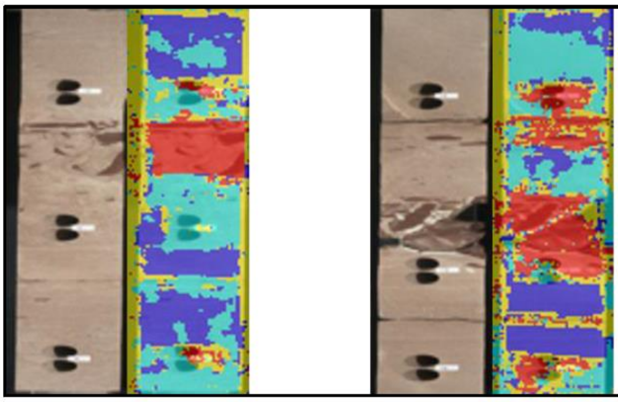
Approach

In present study, data from Rotliegend reservoirs of offshore UK-Netherlands was used. We achieve good accuracy in core automation by using a Convolutional Neural Networks (CNN), which are a type of Deep Neural Network. They are the appropriate class of Deep Neural Networks here because in the present study the goal is to identify the facies from the core images. Facies are classified from the pixels as a result of which each pixel has a facies class assigned (Figure 1:Figure 1). This kind of task where each pixel of an image is classified into the classes of the classification problem is called Semantic Segmentation. It has been used in Robotic vision, autonomous driving, medical imaging, to name a few.

CNN uses a series of convolutions and max pooling. Convolutions are application of a spatial filter on the image pixels which extracts features from the image. Max Pooling is an aggregating step, which reduces the image by extracting a representative pixel value from a region of collection of pixels. This step implements a mapping from high resolution image to a low-resolution feature image. To improve on this a CNN called Segnet is used which takes in a high-resolution image and outputs classes without the loss of resolution. Segnet models the appearance, shape and spatial relationship between different classes. The network identifies objects of various sizes varying from small to large. Also, since the facies are in conjunction with each other in a core image, it is crucial to be able to maintain the boundary relationship between features, allowing to take advantage of co-occurrence of certain type of facies, which are dependent on geological setting.

Results

As this is a supervised classification problem, in which a deep learning model is trained on images with identified classes, first the classes were marked in the images for training purposes. The data was divided into a 70-30 training to test ratio. The images were pre-processed to make them suitable for use for the CNN architecture. Following this, each of the image in the training set were individually labelled for all the classes. After this, the CNN network was trained using the training data. Adam optimization was used. After testing on varying epoch sizes, 100 epochs was observed to give a 70% accuracy in prediction (Figure 2). These results were in turn used with existing robust facies classification of Rotliegend reservoirs along with wireline logs and then applied to wells where detailed facies classification is not applied to core.



Class	Color
Sand	
Sand shale	
Stratified sand	

Figure 1: Two images showing the core images on right and the classified images

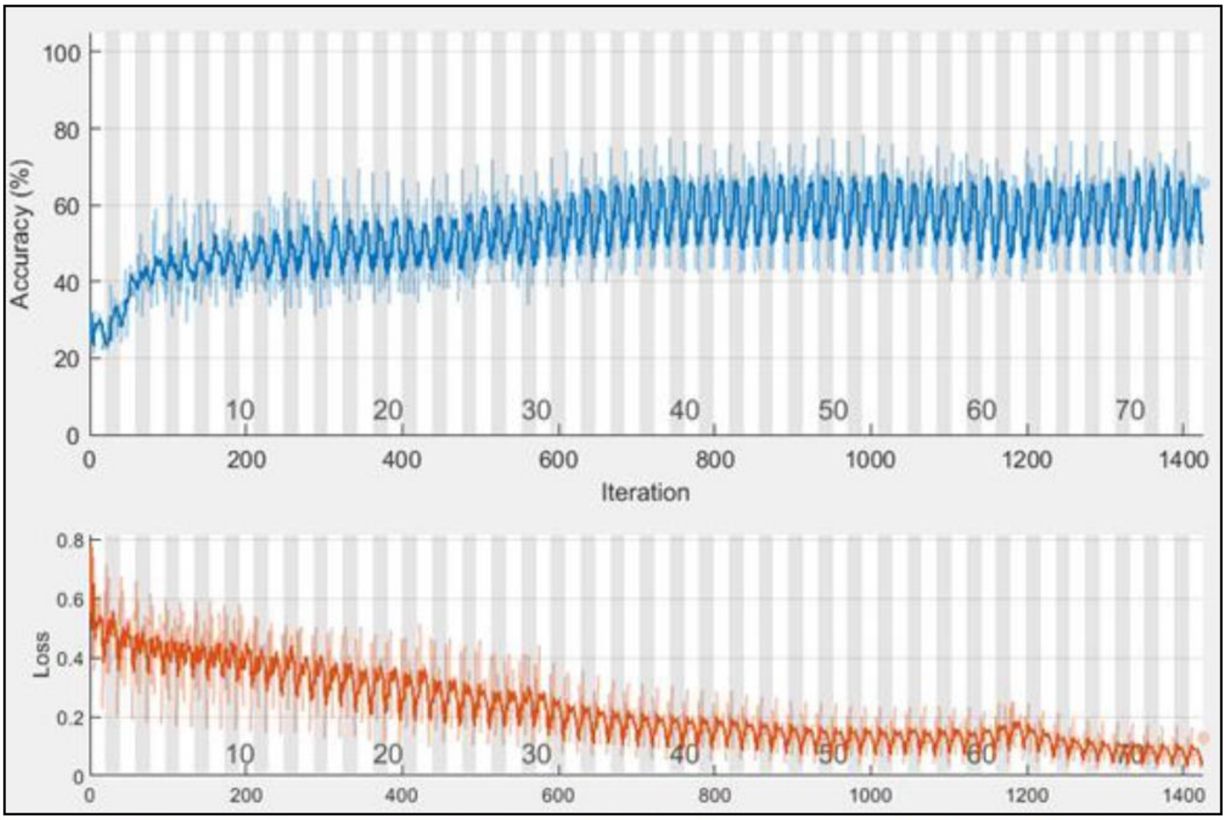


Figure 2: The top curve in blue shows how the accuracy increases with each epoch and the bottom panel shows how the loss decreases

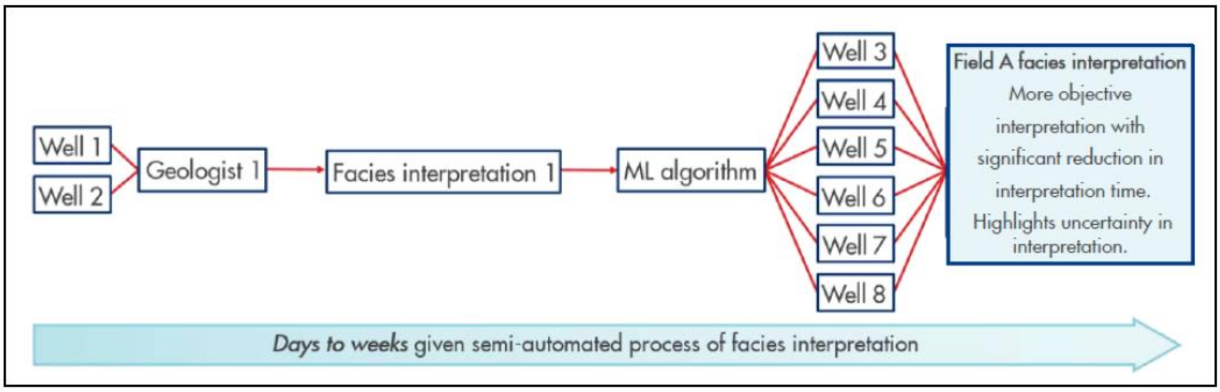


Figure 3: Semi-automated facies interpretation workflow and its advantages

The Future of Core Analysis

Craig Lindsay – Core Specialist Services Limited

Studies of the near sub-surface often focus on the properties of porous media. In the realm of hydrocarbon storage and production, petrophysicists, reservoir engineers, geologists, and geophysicists all study porous media. Core analysts make direct measurements on porous media (core) which enable the associated sub-surface disciplines to build and calibrate their predictive models.

Core analysts examine storge, flow and saturation properties of porous media – whilst some of these measurements are specific to the evaluation of hydrocarbon storage and production (such as input to petrophysical models) many have extensive commonality not only with other sub-surface disciplines – such as hydrology, soil science and geothermal energy – but a very wide range of everyday scientific applications – such as pharmaceuticals, construction materials, catalysts, ceramics and many more. It is therefore apparent that core analysis skills and knowledge have a bright future above and beyond the traditional applications.

There are three key strands to the future of the discipline of core analysis;

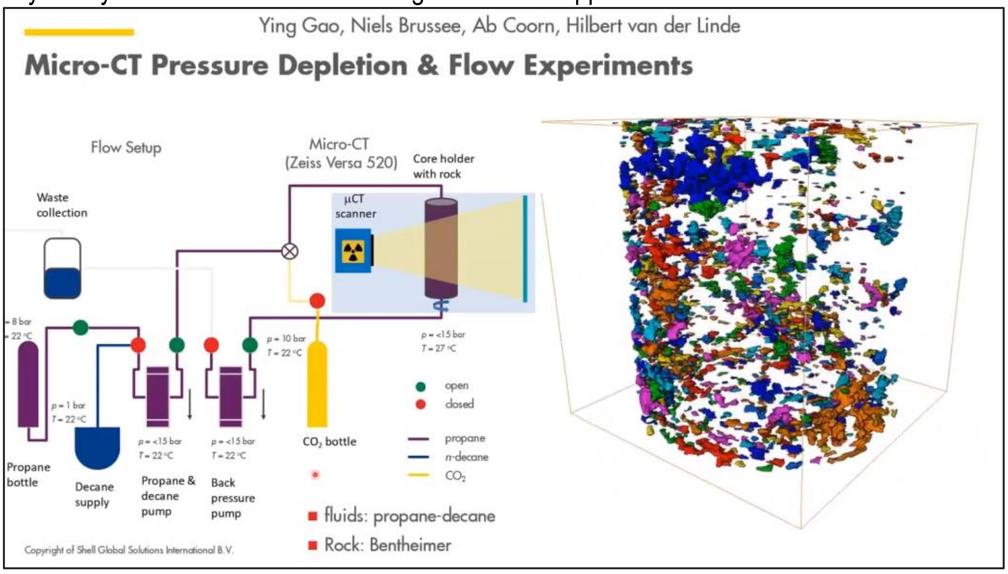
“Traditional” laboratory experimentation will continue to have a key validation role extending beyond hydrocarbon extraction into carbon capture and storge (CCS) and geothermal

The field of digital rock physics has finally achieved the capability to visualise wetting phase and multi-phase fluid mobility phenomena on a pore scale – this will have applications both within the upstream hydrocarbon industry but also in many other wider applications

Traditional core analysis methods have utilised a very small fraction of the data available from core. Technologies now available - under the umbrella term of automated multi-sensor core logging – mean that the ability to characterise core is now orders of magnitude more effective. Moreover, these methods can be applied to core in the many repositories worldwide. This represents a revolution in our ability to understand the sub-surface to the wider benefit of industry and society outwith hydrocarbon extraction.

Core analysis will continue but have a much wider scope and a much greater level of interlock with a wide range of other applications under the remit of the study of porous media.

The presentation will illustrate the technologies that are bringing about the transition of the discipline of core analysis beyond hydrocarbon extraction allowing much wider applications and benefits.



KEYNOTE: The future for core: its value during the energy transition and beyond

R.J. Porter
Nederlandse Aardolie Maatschappij B.V., Schepersmaat 2, 9505 TA Assen, The Netherlands

Petroleum-related samples, including core, drill cuttings and thin section material, continue to provide an invaluable resource in the evaluation and de-risking of hydrocarbon reservoirs. As oil and gas fields approach the end of their productive lives, the value of continued storage of these materials can be questioned by licensees. This can potentially lead to the disposal of excess material, once regulatory requirements have been fulfilled. Core and associated geological data, however, is still crucial in evaluating the sub-surface in the transition to lower-carbon energy. As illustration, the use of geological samples in the following aspects of the energy transition will be considered. 1) During hydrocarbon field decommissioning, geological focus is moved from the reservoir interval to understanding the overburden geology and identifying zones of flow potential and associated caprocks. Legacy core material therefore plays a vital role in this assessment, and therefore in safe, environmentally sound and technically successful well decommissioning. 2) The appraisal and development of geothermal energy opportunities can share many similarities to traditional oil and gas prospects. Core data is therefore an important component in de-risking drilling hazards and predicting temporal and spatial changes in reservoir properties. 3) Hydrogen Storage in geologically porous formations also requires a comprehension of reservoir heterogeneity and mineralogical rock composition. The latter is essential in understanding inorganic hydrogen-mineral reactions that can lead to, for example, H2S generation. Here, petrographic slides and preserved core samples can be key data sources. 4) A comparable consideration of the reservoir composition may also be required when assessing the suitability of carbon capture and storage options.

The crucial importance of core for carbon capture and storage (CCS) projects

Richard H Worden*, Michael J Allen, Dan R Faulkner, James E P Utley

Department of Earth Ocean and Ecological Sciences, University of Liverpool, L69 3GP, UK

Carbon capture and storage (CCS) initiatives, to mitigate greenhouse gas emissions, are being planned for offshore settings in the UK utilising the core that was originally collected to help with oil and gas exploration, appraisal and development projects. Core is essential during the design of CCS projects to make sure that correct decisions are made to optimise injectivity and to choose the most secure long-term storage sites. The objectives of core-based studies for CCS are subtly different to those for oil and gas studies.

It is important to characterise the porosity of CCS reservoirs, which of course is possible using core description and core analysis. Note that wireline log analysis may be adequate to determine porosity in the high porosity and massive Lower Cretaceous, Cenozoic and Triassic sandstones that are currently being high-graded for CCS. The sedimentary architecture of CCS storage sites needs to be understood to predict plume movement patterns, with core description providing essential ground-truthing of log-derived facies interpretations.

Core is essential for reservoir permeability analysis as it provides data required to predict CO_2 injectivety and CO_2 plume movement rates. Core from top-seals is most valuable for CCS projects to determine their flow characteristics and pore geometries, e.g., using mercury porosimetry, to assess seal capacity and calculate maximum CO_2 column heights.

Core is also essential to measure the geomechanical attributes of the CCS reservoir to characterise the conditions under which failure would occur as fluid pressure increases in the vicinity of injection boreholes. Core through CCS top-seals is required to measure the geomechanical attributes of the seal lithologies to determine the conditions under which top-seal failure might occur. Hydrofracking borehole walls due to excess CO_2 injection pressures would lead to problems of injectivity so that rock strength measurements from core are essential to optimise the rate of injection of CO_2 without damaging the reservoir. Characterisation of any faults observed in core in reservoir or top-seal can also be fed into CCS models although image logs will also provide important data through a greater volume of rock.

Core is required to determine reservoir mineralogy and rock fabric for CCS sites using various rock characterisation techniques (petrography, CT-scanning, etc) to assess whether the host reservoir may undergo partial dissolution in the near well-bore region. Core-derived mineralogy and fabric data can be used with reaction-flow models to predict dissolution-enhanced porosity and possible weakening of the near well-bore region. Core samples could also be used for CO_2-water flow-through experiments to assess alteration to matrix grain, mineral cements or to assess whether halite precipitation occurs from saline formation waters as anhydrous CO_2 dehydrates the reservoir.

KEYNOTE: The value and importance of core to subsurface understanding, uncertainty and risk management in upstream E&P – business impact and future challenges

Mike Bowman
School of Earth & Environmental Sciences
University of Manchester

Core represents the only 'hard' host rock data available to test and calibrate the diverse suite of indirect and AI based measurements and observations that underpin subsurface characterisation. It impacts upon the evaluation of all areas of applied subsurface energy systems from upstream oil and gas and minerals exploitation to dispersal of waste products such as nuclear waste, climate monitoring and engineering site assessment. In the upstream oil and gas industry the cost and value of all data acquisition must be considered in the context of its business impact, and the commercial value gained through the reduction of uncertainty and management of risk.

Historically the justification for acquiring core was relatively easier and often largely based upon a technical case and justification. Today we are confronted by increasing costs, together with challenging and complex subsurface environments, a deeper understanding of operational risks and the need to minimise the environmental footprint of all subsurface activities. This demands a more value and business impact-based justification to acquire core. The subsurface professionals must understand the links between their technically-based case (the Integrated Subsurface Description, ISD) and the business processes it informs (the field/reservoir depletion plan), clearly and quantitatively articulating the impact and value of coring and how the core will help the reduction of relevant uncertainties and the effective management of risk. Equally important is the timely acquisition of the data to achieve maximum impact. The Depletion Plan provides the link between the technical case and the business process and as such will be the basis of any coring case. Understanding the changing focus in depletion plan activities across the upstream value chain and where critical uncertainties and risks lie in the viable and safe exploration, development and production of a reservoir/field are key pre-requisites to justify all data acquisition, particularly higher cost and often operationally more risky activities such as coring.

Today and looking forward, the increasing use of AI and data analytics enables viable digital rock definition, placing increased pressure on the justification for acquiring core. Even here, core remains a critical calibration underpinning the AI and digital characterisation. Without core, particularly in complex reservoirs where field to pore scale heterogeneity plays a significant part in recovery efficiency due to variations in relative permeability, saturation and flow properties, the level of uncertainty and resultant risk to commerciality may be unacceptably high. The challenge is to ensure subsurface professionals have a depth of understanding and insight into the impact of the rock/fluid uncertainties and risks to justify the value and need for core.

The challenge is being exacerbated as the upstream industry shifts focus from exploration and new field development to meeting environmental emission challenges, extracting more out of existing fields or reservoirs and accessing by-passed resources. Subsurface teams will need to enhance their development of down-value-chain expertise and skills, effective knowledge of uncertainty and risk, as well as commercial and HSE capability. This talk examines these challenges using examples to illustrate the current and future challenges including AI and digital rocks.

Virtual Core Sessions

Day 1

Iraq vCore demo: Early Cretaceous deltaic deposits of the Zubair Formation: Depositional controls on reservoir performance
Martin Wells, BP

North Sea Core Demo
Henk Kombrick & Kirstie Wright

Day 2

The Montot-1 Core, Ainsa Basin, Spanish Pyrenees: a deltaic reservoir teaching set with augmented reality
John Marshall, Jurgen Grötsch, Michael Poppelreiter, Shell
Mondot-1 was cored a combined effort between Shell, Schlumberger and the University of Barcelona, and features in the 2020 EAGE volume "Digital Geology". It was cut across the Eocene Sobrabe Formation, a fluvial-dominated delta system prograding over a carbonate platform.
We will start with an introduction to the geological setting, followed by a walk-through of the core itself to highlight some of the key features. We shall look at the link between core and open-hole logs, reservoir properties and structural features.

Days 2-4

Unconventional Reservoir Characterisation
Patricio Desjardins, Shell
Anton Padin, Total
Claudia Ruiz-Graham, Imaged Reality
Learn about recent advances in characterization methods and technologies developed for unconventional reservoirs. Workshop participants will interpret and integrate core photos, thin sections, SEM images, logs and core analyses from Vaca Muerta (Argentina) and Permian Basin (US) reservoirs; delivered using 3DGaia, a multiuser, interactive, remote collaboration platform for geoscience, developed by Imaged Reality.
Discussion will focus on the assessment of key reservoir properties and their impact on hydrocarbon distribution, hydraulic fracture behaviour and producibility.

Day 3

Late Permian dryland core: applications to sub-surface energy storage assessment
Richard Porter, Nederlandse Aardolie Maatschappij B.V
Martin Grecula, Shell
Sub-surface energy and carbon storage is expected to make an important contribution in the transition to a lower-carbon world. To assist in enabling ongoing and future projects, core and other geological samples will play a crucial role in de-risking potential reservoirs and seals. This virtual core workshop examines Late Permian Rotliegend core from the Netherlands, with a variety of dryland palaeoenvironments displayed. Key features of the core will be examined and their importance related to de-risking potential storage opportunities addressed.

Day 4

Iraq vCore demo: Late Cretaceous shallow marine carbonates of the Mishrif Formation: depositional and diagenetic controls on reservoir performance
Anna Matthews, BP

GSL CODE OF CONDUCT FOR MEETINGS AND OTHER EVENTS

INTRODUCTION

The Geological Society of London is a professional and learned society, which, through its members, has a duty in the public interest to provide a safe, productive and welcoming environment for all participants and attendees of our meetings, workshops, and events regardless of age, gender, sexual orientation, gender identity, race, ethnicity, religion, disability, physical appearance, or career level.

This Code of Conduct applies to all participants in Society related activities, including, but not limited to, attendees, speakers, volunteers, exhibitors, representatives to outside bodies, and applies in all GSL activities, including ancillary meetings, events and social gatherings.

It also applies to members of the Society attending externally organised events, wherever the venue.

BEHAVIOUR

The Society values participation by all attendees at its events and wants to ensure that your experience is as constructive and professionally stimulating as possible.

Whilst the debate of scientific ideas is encouraged, participants are expected to behave in a respectful and professional manner - harassment and, or, sexist, racist, or exclusionary comments or jokes are not appropriate and will not be tolerated.

Harassment includes sustained disruption of talks or other events, inappropriate physical contact, sexual attention or innuendo, deliberate intimidation, stalking, and intrusive photography or recording of an individual without consent. It also includes discrimination or offensive comments related to age, gender identity, sexual orientation, disability, physical appearance, language, citizenship, ethnic origin, race or religion.

The Geological Society expects and requires all participants to abide by and uphold the principles of this Code of Conduct and transgressions or violations will not be tolerated.

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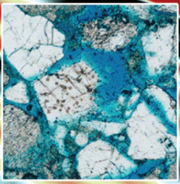
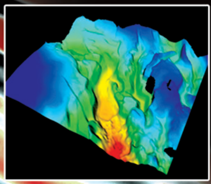
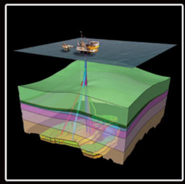
If an incident of proscribed conduct occurs either within or outside the Society's premises during an event, then the aggrieved person or witness to the proscribed conduct is encouraged to report it promptly to a member of staff or the event's principal organiser.

Once the Society is notified, staff or a senior organiser of the meeting will discuss the details first with the individual making the complaint, then any witnesses who have been identified, and then the alleged offender, before determining an appropriate course of action. Confidentiality will be maintained to the extent that it does not compromise the rights of others. The Society will co-operate fully with any criminal or civil investigation arising from incidents that occur during Society events.

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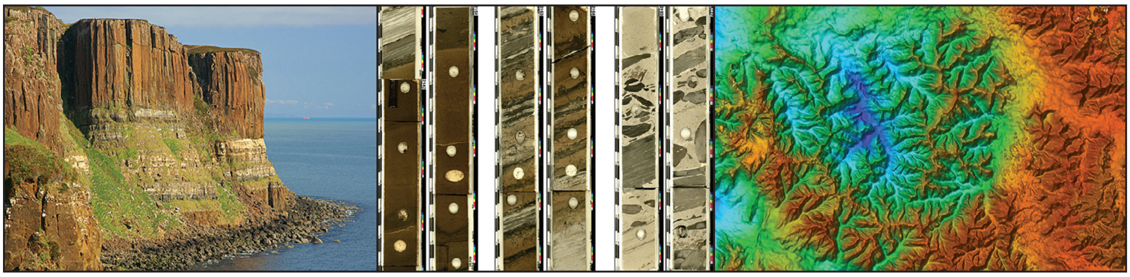
Registration Open

New learning from exploration and development in the UKCS Atlantic Margin

19 - 21 May 2021

Virtual Conference, Zoom, BST



The UK Atlantic margin, including the West of Shetlands area, is the location of the UK's largest remaining hydrocarbon reserves, the largest recent field development investments and holds the greatest potential for future material discoveries in the UK.

In the 10 years since the last Geological Society conference on this region, great advances have been made in the understanding of its diverse plays, from fractured basement to Eocene coastal deposits, and everything in between.

This three day meeting (19-21 May) gives a unique opportunity to learn about the geoscience of recent discoveries and field developments, as well as how technology is developing to meet the imaging and drilling challenges of the area. For a fully immersive experience, there is an opportunity to see the diverse range of reservoirs in outcrop in a virtual field trip to the Isle of Skye (13-14 May) and in core at a half-day virtual guided core viewing (18 May).

Conference themes:

- Regional and exploration perspectives
- Basement and Palaeozoic reservoirs
- Mesozoic pre-, syn-, and post-rift plays
- Volcanic associated reservoirs
- Paleocene deep water reservoirs
- Multidisciplinary technology session
- Geodynamics, basin modelling, thermal and uplift/subsidence history, migration routes
- Government perspective

Associated events:

- Two day field trip to the Isle of Skye run by Aberdeen University (13-14 May), examining the strata of the Hebridean Basins in a petroleum systems context, as analogues for the basins West of Shetland.
- Half-day virtual guided core viewing (morning of 18 May), looking at selected cores from throughout the stratigraphy of the West of Shetlands area.

For further information please contact:

Sarah Woodcock, The Geological Society, Burlington House, Piccadilly, London W1J 0BG. Email: sarah.woodcock@geolsoc.org.uk
Web: https://www.geolsoc.org.uk/05-rescheduled-pg-atlantic-margins-2021

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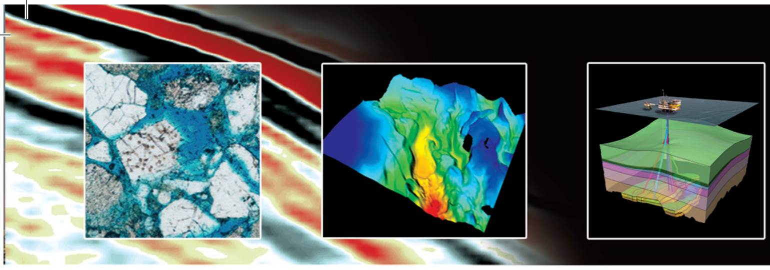

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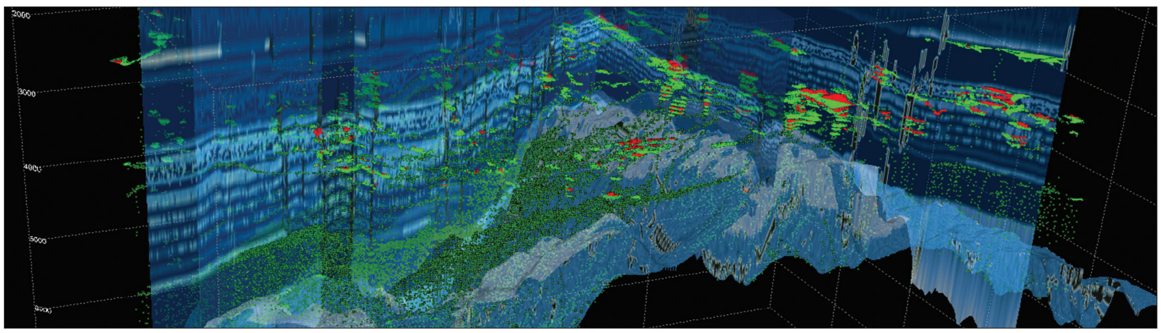
Call for Abstracts - Extended Deadline 31 May 2021

Basin and Petroleum Systems Modelling

Best Practices, Challenges and New Techniques

28 - 30 September 2021

The Geological Society, London and Virtually



The prediction of viable petroleum systems is critical to meet the growing energy demand. At the same time, the energy sector is shifting from traditional hydrocarbon to alternatives, and new disciplines such as carbon capture and storage are emerging. This meeting will discuss the importance of Basin and Petroleum System Modelling (BPSM) in exploration and evaluation of resources, focussing on best practices, recent developments, novel applications, and opportunities for the future. New and improved digital capabilities have enabled a more integrated approach to analysis; therefore, the impact of newly available data and technologies in BPSM will be reviewed.

BPSM key topics

- Best practices in different exploration scenarios: mature, frontier, and unconventional areas
- Effectiveness of modelling geological processes: heat flow; erosion; kinetics; thermal conductivity
- New techniques in BSPM
- Linking to new disciplines: carbon capture and storage; reservoir engineering; geothermal; and more
- Dealing with predicted risk and uncertainty
- Charge and migration modelling
- Case studies

The conference will bring together professionals from academia, government agencies, and industry to discuss BPSM through a series of presentations and panel discussions, suitable for both a specialist basin modeller and for a general exploration geologist. A dedicated student short talk will encourage participation from a new generation.

Convenors:

Christine Yallup
Halliburton

Rachel Round
Halliburton

Michael Abrams
Imperial College London

Friedemann Baur
Chevron

David Gardiner
IGI

Rachel Gavey
APT (UK)

Daniel Palmowski
Schlumberger

Will Prendergast
Independent Consultant

Dani Schmid
Geomodelling Solutions

Robert Newbould
Premier Oil

Keynote talks:

Zhiyong He
Zetaware

Neil Frewin
Shell

For further information please contact:

For more information please contact Sarah Woodcock, sarah.woodcock@geolsoc.org.uk, or visit the conference website: https://www.geolsoc.org.uk/09-rescheduled-pg-petroleum-systems-modelling-2021

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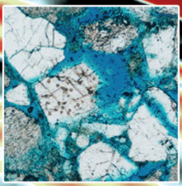
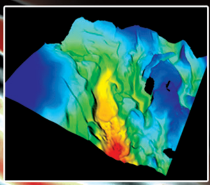
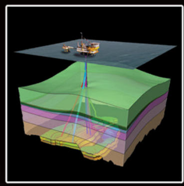

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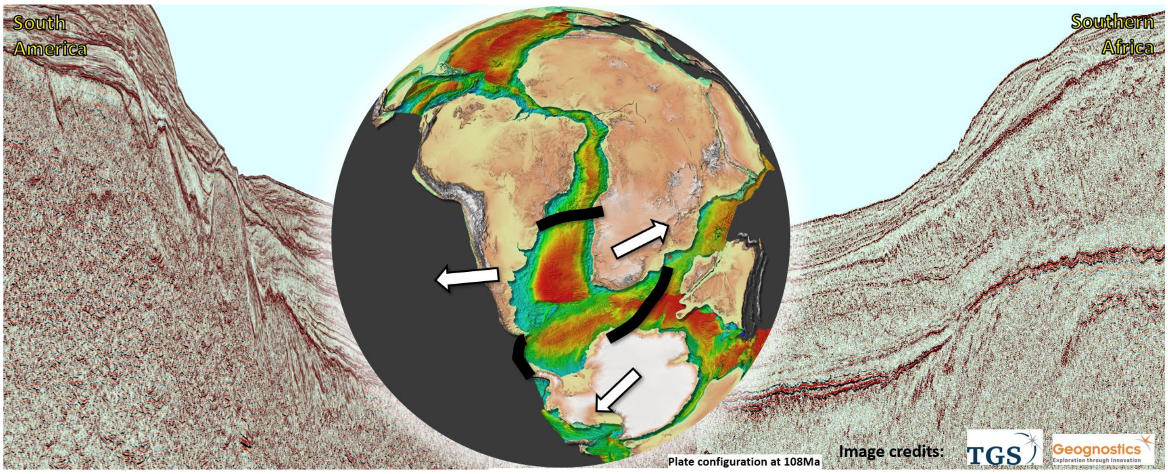
Call for Abstracts

Petroleum Geology of the Southern South Atlantic

6-8 October 2021

The Geological Society London



There has been a significant increase in interest towards the Southern South Atlantic by the exploration community in the past few years. Significant resources have been discovered in Falklands/Malvinas (Sea Lion, 2010) and South Africa (Brulpadda & Luiperd, 2019 & 2020) as well as commercial success in the 1st Argentina offshore licensing round (2018).

This three-day conference aims to bring together both academic and industry geoscientists to discuss the current state of understanding of the geology and petroleum systems in this emerging petroleum province. Topics ranging from plate- to prospect-scale will be covered.

The committee welcomes the submission of abstracts on the following themes:

Day 1 - Tectonics & Regional Processes
Plate modelling, dynamics of mantle & topography, inherited structures & controls on source rocks, rifting, volcanism & SDR development

Day 2 - Play Elements
Source to sink, source rocks, thermal & basin modelling, deep water clastic reservoir rocks, carbonates, contourites, oceanography and ocean gateways

Day 3 - From Prospect to Discovery
New play types & models, thermal controls on reservoir systems & exotic fluids, uncertainty modelling in frontiers, operational challenges, new data techniques & technologies, technical advances in source rock prediction & thermal modelling

For further information please contact:

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