Reducing uncertainty and risk through field-based studies

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Abstract: Field-based studies, be they regional or basin-scale fieldwork, or the examination of outcrop analogues, have been an important component of petroleum system studies in the upstream oil and gas industry for many years. Recent technological advances, founded on traditional field methodologies, whether they are in digital outcrop characterization or developments in processing and computational capabilities, have fuelled a resurgence in such fieldwork. These studies enable the building of realistic models that allow the exploration or production geoscientist to navigate effectively from plate-to-play-to-pore. The interrogation of field data and resulting models provide a more informed means of benchmarking the subsurface, as well as a more realistic view of subsurface uncertainty and the management of associated risk in subsurface description and prediction.

This Special Publication records 12 papers given at a conference titled ‘Reducing Subsurface Uncertainty and Risk Through Field-Based Studies’ organized by the Petroleum Group of the Geological Society of London, and held in London from 4 to 6 March 2014. The observations drawn in this introductory paper reflect the authors’ experiences, presentations at the conference and manuscripts within this volume.

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Reducing uncertainty and risk through field-based studies

This volume showcases the value of field-based studies in reducing uncertainty and risk in hydrocarbon exploration and production, and, as such, it is a companion to the volume Sediment Body Geometry and Heterogeneity, edited by Martinius et al. (2014). The papers include examples of stratigraphic and structural studies, outcrop analogues, field data developing play analogues, and the application of modern techniques such as LiDAR (Light Detection And Ranging) and 3D photogrammetric analysis. The studies were undertaken in geographically diverse locations such as the Faroe Islands, Italy, Algeria, India, the USA and Trinidad (Fig. 1), representing a range of tectonic settings and a wide geological time frame.

The integration of field-based studies into the exploration or production workflow is not a new concept; the conference that preceded this volume ‘Reducing Subsurface Uncertainty and Risk Through Field-Based Studies’ was convened in response to the resurgence in these studies and the adoption of new technologies. The conference was held over 3 days at the Geological Society in Burlington House, when 40 papers were presented (Bowman et al. 2014). The 12 papers that comprise this volume offer an excellent reflection of the range in scope and topics offered at the event. The meeting reflects the upturn in interest in field-based studies over recent years, and how these are being used to better reflect subsurface uncertainty and to manage risk for subsurface description and prediction in the upstream oil and gas industry. This is, in part, a reflection of the major advances in capturing and visualizing outcrop data through the advance of techniques such as LiDAR technology combined with a more ‘user-friendly’ ability to create meaningful numerical and digital characterizations of these data which are of more direct value to subsurface practitioners, specifically in the upstream oil and gas industry.

The papers in this volume have an applied focus for the upstream oil and gas industry. They mainly relate to applications in the exploration, appraisal and development phases of the business. In addition, there are a limited number of technique-based papers that reflect some of the advantages available to geoscientists today in terms of digital technology, data manipulation and visualization. Every field-based study carries the expectation of safety management, an area addressed by Gill & Lynn (2015); it is a critical topic that has appropriately received greater attention in recent years, reflecting the oil and gas industry’s increased focus on this aspect of their risk management.
Outcrop analogues and field studies have been an important part of petroleum-system-related studies in the upstream oil and gas industry for many years. This need to understand the entire system harks back to the very earliest days of our industry in such places as East Texas, the Middle East and the South Caspian, informing the decisions on where to drill exploration wildcat wells in frontier areas that led to the birth and growth of the upstream industry we know today.

In these early days, the use of field data was largely based on qualitative observation, maps and diagrams that offered general insights into the petroleum system of an area, particularly focusing on improved exploration for working source rocks and potential reservoir systems. It was the advances in computational technology in the late 1980s that enabled a step change in how and why geoscientists collected and used the data. This change resulted in more informed and, consequently, better business decisions, and an enhanced subsurface understanding. The development of numerical modelling and characterization techniques enabled geologists and other subsurface practitioners to transfer their previously qualitative field observations and descriptions into numerical data. Stochastic modelling, the application of statistical and more deterministic techniques enabled insights into the size, shapes and architecture of different depositional bodies. This is reflected in some of the seminal and classical works of Weber & van Guens (1990), Begg & Williams (1991), Haldersen & Damsleth (1993) and Hirst et al. (1993). This created a new branch of geoscience and saw the first recognized applied computational geologists, able to transfer the traditional qualitative observations into digital data. These new numerical static descriptions could be upscaled and transferred into simulations and predictions of reservoir performance by reservoir and petroleum engineers including Haldersen et al. (1987), Dubrule (1989) and Geehan & Pearce (1994). The data, associated models and interpretations have enabled a deeper understanding of the nature and range of subsurface uncertainties, and how these impacted risks to delivering promised resource assessments, reservoir production profiles, production forecasts and well rates (Fig. 2) (Fox & Bowman 2010).

Since about 2000, developments in computational capability, data capture, visualization and uncertainty assessment have lead to major changes in the way geologists worked, placing greater demands on numerical and computational skills. These advances have also lead to a massive explosion in fieldwork as academia and industry revisited classic outcrops and sought out new field areas to deliver detailed descriptions and maps that could be readily quantified in digital format. The classic works in areas such as the Book Cliffs (Hampson et al. 1999; Hodgetts & Howell 2000), Karoo deepwater and slope systems (Flint et al. 2011), carbonates (Ruppel 2012), and elsewhere (e.g. Reynolds et al. 1998; Hampson et al. 2008) reflect this new dawn in applied data collection. It was largely focused on reservoir systems, where the digital static description of the outcrops became the initial context.

**Fig. 1.** World map illustrating the range of papers offered in this volume.
and core part of a subsurface workflow focused on permeability architecture description, modelling and prediction (Fig. 3).

The industry driver behind this new growth in subsurface description and understanding was the move to new, more challenging areas for exploration and production. Offshore developments in more challenging regions, such as the North Sea, shifted focus to drilling fewer, often high production-rate wells from typically space-constrained offshore production and drilling facilities in increasingly deeper water, with complicated geology and challenging metocean conditions. All of this put pressure on the subsurface team to focus more on optimally placing the wells drilled, deeper consideration of recovery mechanisms and their impact on reservoir drainage, sweep efficiency, and recovery factors (Fig. 4). The arrival of numerical characterization enabled the geologist to transfer their historically qualitative descriptions into more useful numerical models that also facilitated this more rigorous approach to understanding subsurface uncertainty and risk management. The early work was largely focused on the exploration, appraisal and development phases of the business where major strategic and commercial decisions are made, driven largely by the subsurface description, particularly of the reservoir system and its impact on permeability architecture (Weber & van Guens 1990; Gluyas & Swarbrick 2004; Jahn et al. 2008).

Following these advances and changing business demands, a whole range of field-based research efforts began to describe more rigorously the outcrops around the globe as analogues for subsurface prospects, discoveries and fields. This boom also lead to a number of significant advances in our understanding of reservoir depositional systems, focusing more on siliciclastics initially (Reynolds et al. 1998; Richards et al. 1998; Richards & Bowman 1998) but also including some seminal works on carbonates (Lucia 2007; Ruppel 2012). These exercises by research groups, such as the North Africa Research Group (NARG) at the universities of Manchester, Heriot-Watt and Delft, and the University of Aberdeen and many others besides, were almost exclusively funded by industry.

Today, the hydrocarbon industry finds itself once more at a tipping point, with returns on investment under pressure: explorers are required to resolve ever-more challenging reservoir issues with greater precision, while the business demands for lower costs has led to increased focus on understanding the subsurface, which, in turn, results in better informed business decisions. The resolution, speed of accessibility of techniques such as LiDAR (Hodgetts 2013), photogrammetry and GIS (geographical information systems), along with supporting software, have evolved significantly in recent years; combined with major advances in computational capability and high-performance computing.

**Fig. 2.** Subsurface uncertainty and risk-management high-level workflow illustrating the impact of fundamental uncertainty sources (resource size, well rate and production profile) on key E&P value chain decision points.
centres becoming the norm in the industry, subsurface visualization and digital description has now become routine (Seers & Hodgetts 2014; Pyrcz & Deutsch 2014). With a requirement for sound input data, these advances have led to a resurgence in outcrop description and characterization. At the same time, the demands of industry for better numerical descriptions, characterizations and integration of the subsurface were being driven by stepouts into deeper water, more complex geology, deep high-pressure and high-temperature environments, unconventional reservoirs such as shale gas and

**Fig. 3.** Fundamental subsurface workflow for a reservoir description that illustrates the foundation that outcrop studies have as an input to describing, distributing and modelling permeability (adapted from a figure provided by A.J. Pulham).

**Fig. 4.** Scales of dynamic focus using outcrop studies and their relevance to subsurface performance: outcrop scale is the focus of this Special Publication.
oil, and a high cost base. Together, these have meant that the time was right to take another step forward in reducing subsurface uncertainty and risk through field-based studies as a basis for better and more informed business decision making.

This volume, and the conference that led to its compilation, was instigated in response to the latest advances in capability and demand for high-quantity field-based studies. It covers most, if not all, of the latest techniques and how they are applied. The papers in this volume cover the full range, from frontier basin petroleum system assessment (Racey et al. 2016) to field appraisal and development (Bowman et al. 2014; Hirst 2016), covering structure, stratigraphy and also unconventional resources.

This volume is structured to present the papers in four sets around the following themes:

- health and safety in the field;
- fieldwork in frontier and mature basins;
- fieldwork techniques, current application and new developments;
- uncertainty characterization.

**Health and safety in the field**

The opening paper of this Special Publication is a timely and thought-provoking paper on health and safety in the field (Gill & Lynn 2016). This paper considers fieldwork safety practices and their management from a Shell perspective. Field safety rightly occupies a more prominent place in our thinking for fieldwork today (e.g. Oliveri & Bohacs 2005). The best practices, often commonsense approaches, are not always adhered to; this paper presents an opportunity to reflect and learn skills that are relevant to those in our industry who are responsible for the safety of participants, be they students or colleagues in the field.

**Fieldwork in frontier and mature basins**

The paper by Racey et al. (2016) offers an example of fieldwork applied to frontier exploration informing the understanding of an integrated petroleum system. This shows how field data are used to help aid basin entry and the early stages of exploration access decisions.

Vosgerau et al. (2015) present results from fieldwork on the Faeroe Islands Tertiary volcanic system. This paper explains the application of photogrammetry and how it is being used in a complex, intra-volcanic exploration target. The work serves as an excellent analogue for the area exploration focus of West of Shetlands in the UK Continental Shelf (UKCS) and the Norwegian Offshore Continental Shelf (NOCS), which has resulted in the discovery of the Rosebank Field that is currently under development by Chevron (Duncan 2015).

The papers by Hurst et al. (2015) and Rossi & Craig (2016) offer examples of how field-based studies are being used in more mature exploration modes. Hurst et al. (2015) summarize and update consortia work on injectites as possible reservoirs, applying them to the appraisal of the Volund Field in the NOCS. Rossi & Craig (2016) show how outcrop data can be successfully integrated with subsurface data to enable new insights into hydrocarbon plays and reservoir types through the rigorous application of sequence stratigraphic techniques. They look at the impact of relative sea-level changes on reservoir prediction in the NW Italian Alps.

**Reservoir and field development**

Moving along the exploration and production (E&P) value chain into reservoir appraisal and field development, Hirst (2016) and Bowman (2016) offer two very detailed analyses of shallow-marine and wave-dominated shoreline systems in Algeria and Trinidad, respectively. Both are focused on analogues for gas field reservoirs in their areas. Hirst (2016) presents the results of fieldwork in shallow-marine sandstone reservoirs analogues: these sands exhibit complex, non-intuitive architecture that is subseismic and difficult to predict. The paper shows how field studies have helped in understanding the facies, developing a depositional model for such reservoirs and explaining the varied outcomes in the subsurface. Bowman (2016) offers a synthesis of a major effort to describe outcrop analogues of the subsurface reservoir in the Columbus Basin, offshore Trinidad. The paper integrates recent publications on specific aspects of these outcrops (Bowman & Johnson 2015) to offer novel insight into the controls, architecture and predictability of these reservoirs and other analogous high-sedimentation and high-subsidence rate aggradationally dominated shoreline reservoir systems.

Donovan (this volume, in press) offers an insight into how fieldwork and reservoir analogues have materially impacted the understanding and prediction of unconventional source-rock-based reservoir systems (shale oil and shale gas). Using a reservoir-scale outcrop of the Eagleford Group in West Texas, USA, the paper illustrates how detailed outcrop observations and field descriptions can help in predicting sweet spots in subsurface shale reservoir systems. Applying traditional stratigraphic description and prediction techniques to these systems has advanced the understanding of how to drill and develop these unconventional reservoirs more effectively.
Fieldwork techniques current application and new developments

During the conference, several presentations focused on new developments or adaptations of existing techniques such as LiDAR and photogrammetry (see Vosgerau et al. 2015). The other papers in the volume are more diverse, ranging from specific analytical techniques to the value and application of digital mapping to non-oil and gas projects which could be readily transferred to subsurface prediction and description.

The keynote paper by Sanderson (2015) offers an overview of how field-based structural analogues have helped in better understanding the geometry and predictability of post-depositional structural deformation. These techniques have helped constrain the understanding of structural compartmentalization and trap definition.

Papers by Jordan & Napier (2015) and Newell & Shariatipour (2016) illustrate the step changes in digital outcrop mapping that are transforming the mapping work carried out by the British Geological Survey (BGS) in the UK. These papers provide excellent illustrations of the major advances created by using digital techniques, both software and hardware, in traditional mapping. The BGS is at the cutting edge for applying these approaches and actively transferring this capability to other government-funded geological surveys around the world. These papers provide details on the challenges of data management and validation caused by the advance in techniques such as GIS systems, together with numerous other new and diverse data sources.

Uncertainty characterization

The final manuscript by Peel & White (2015) focuses on a key theme of the conference – uncertainty characterization. This paper offers a challenging and thought-provoking discussion into the use of, and abuse of, uncertainty descriptions in the subsurface.

Conclusion

This volume demonstrates the value of field-based studies in reducing uncertainty in hydrocarbon exploration and production. The variety and range of papers is testament to the value and integral position that fieldwork occupies within the hydrocarbon industry. They mark a major milestone in the advances made in using outcrop data to better constrain subsurface understanding and uncertainty management. Future advances are likely to involve computational/processing capabilities, the reduction in cost of technology such as LiDAR, and moves into remote and predictive mapping, as well as photogrammetry from unmanned aerial vehicles (UAVs).

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