The Petroleum Geology of NW Europe: 50 years of learning – a platform for present value and future success. An overview

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The conference ‘50 Years of Learning – A Platform for Present Value and Future Success’ was the eighth in a series that has accompanied the exploration and development of the offshore oil and gas resources of NW Europe since 1974. The 2015 event was timed to mark the 50th anniversary of the first commercial offshore discovery in the North Sea: the West Sole gas field in Block 48/6 off the Humber estuary in the UK sector in 1965 (Winter & King 1991). BP have the honour of being the operator of that discovery well. The conference also coincided with a collapse in oil prices. The Brent crude oil price during the meeting, on 28 September 2015, was $48 per barrel, which compares with $109 on the day of the first Technical Committee meeting on 16 August 2013! In such circumstances, the steadfastness of the conference’s three sponsoring organizations – The Energy Institute, The Geological Society of London and the Petroleum Exploration Society of Great Britain – is to be admired. As, of course, is the generous support, in straitened circumstances, of the corporate sponsors.

The subtitle of the conference, ‘A Platform for Present Value and Future Success’, was chosen to reflect the aim of enabling those Earth scientists and subsurface practitioners currently working on hydrocarbon resources across NW Europe to make optimal use of the considerable past investments in the largely offshore facilities, as well as the scientific understanding and knowledge gained. The ultimate focus is to maximize the safe and effective use of the investments to create and deliver resources for a low-cost energy-hungry society. A modest number of papers also specifically looked forward to the re-purposing of oil and gas facilities for a low-carbon-energy future.

The conference was attended by 530 delegates. These included postgraduate students from the new Doctoral Training Scheme in Petroleum Geology based at Herriot Watt, as well as seven prize-winning Masters students whose attendance was generously sponsored by the late Dave Roberts’ widow, Robin. Two Best Paper awards were sponsored by BP and Shell, and named (with the kind permission of their respective families) in honour of the late Dave Roberts (BP) and Peter Ziegler (Shell). These were awarded to:

- Nick Schofield of Aberdeen University for ‘Intrusive and extrusive sequences and their interactions with hydrocarbon systems – a key geoscience challenge’;
- Fred Hughes, of Third Energy for ‘North Yorkshire’s sleeping giant’.

Conference and proceedings structure

The conference was originally organized around a series of themes covering the full range of the Upstream Oil and Gas Value Chain, and spanning all of the main and less well-known plays and pay fairways. Sessions included, for example, Key geoscience challenges, Key field and fairways, Key geophysics challenges, and Petroleum systems and fairways. Of the 62 oral presenters who gave presentations, 32 authors actually submitted papers. Seven of the poster presenters subsequently stepped up to submit full written papers. Reflecting this, the structure of this volume reflects the

Table 1. Core workshop displays

<table>
<thead>
<tr>
<th>Stratigraphic age</th>
<th>Reservoir/field</th>
<th>Region</th>
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<tbody>
<tr>
<td>Eocene</td>
<td>Catcher</td>
<td>28/9a-6 UKCS Northern Sea</td>
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<tr>
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<td>28/9a-2</td>
</tr>
<tr>
<td>Eocene</td>
<td>Intra-volcanic</td>
<td>Outcrop samples</td>
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<td></td>
<td>sands</td>
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<tr>
<td>Eocene</td>
<td>Schiehallion</td>
<td>204/20-1 West of Shetlands</td>
</tr>
<tr>
<td>Paleocene</td>
<td>Nelson</td>
<td>22/11-N1 UKCS Central North Sea</td>
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<td>22/11-N9</td>
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<td></td>
<td></td>
<td>21/11-N16y</td>
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<tr>
<td>Cretaceous</td>
<td>Goldeneye</td>
<td>14/29a-3 UKCS Moray Firth</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Buzzard</td>
<td>4B 20/01-8 UKCS Moray Firth</td>
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<td>4C 20/06-4</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Ettrick</td>
<td>20/02a-E5 UKCS Moray Firth</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Harelv Formation</td>
<td>Bloklev1-1 Greenland Outcrops</td>
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<tr>
<td>Jurassic</td>
<td>Magnus</td>
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<tr>
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<td>Shearwater</td>
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<td></td>
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<td>22/30b-A6</td>
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<tr>
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<td>Brent</td>
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<td>Permian</td>
<td>Cygnus</td>
<td>44/12a-4 UKCS Southern North Sea</td>
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<td>Carboniferous</td>
<td>Cygnus</td>
<td>44/12a-3 UKCS Southern North Sea</td>
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<td>Welton A14 UK Onshore</td>
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<td>Welton B09</td>
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<tr>
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<td>Wingate</td>
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<td>44/24b-7</td>
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<td></td>
<td>44/24b-A4</td>
</tr>
<tr>
<td>Devonian</td>
<td>Clair</td>
<td>206/8-11A West of Shetlands</td>
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<td>206/8-A02</td>
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broad themes of the conference, but is organized slightly differently from the conference sessions:

- Plays and fairways;
- Play assessment;
- Recent successes and learnings from failures;
- Infrastructure-led exploration and development;
- Late-life fields, re-development and the next life;
- Onshore exploration and development.

These reflect a balance of industry and academic contributions across the NW European region.

The conference also included a core workshop; the convenors felt strongly that the opportunity to examine core is a fundamental part of realizing the aims of the conference, as in previous events. The cores were carefully selected to cover many of the major plays, reservoirs and play fairways in the region. It comprised a balance of classic reservoirs, as well as more recent successes. The cores on display are listed in Table 1. Whilst the core workshop presentations are not included in this volume, there are papers on Welton (Stevenon & Bowman 2016), Cygnus (Catto et al. 2017), Shearwater (Jones et al. 2017) and Goldeneye (Marshall et al. 2017), which refer to some of the cores on display.

Proceedings overview and summary

Overall, the papers and posters suggest that both the North Sea 50 years on and the broader region still have real upsides despite their overall maturity. The diversity of lightly explored plays, the variety of the new discoveries, and of the applications of novel technologies and workflows cited in the volume all demonstrate that there remain many, often innovative, ways to create value from frontier exploration to late field life. Figures 1 and 2 illustrate the range of papers in terms of both the various plays covering the Petroleum Geology of the region and also the Upstream Exploration and Production Value Chain.

The historical technological leadership that NW European operators and researchers established during the early development of the region in the 1970s to mid-1990s continues to be shown in the papers of this volume. There is also evidence that ideas that have been developed and applied to new frontier basins, such as West Africa, the Gulf of Mexico and other areas, are being brought to bear to create future value in a number of the NW European basins and fields. The value of seismic is clear in many of the papers (Porcupine, Watremez et al. 2016; Rosebank, Poppitt et al. 2016; and Huntington, Edwards et al. 2017 and Wright et al. 2017 are good examples). Challenging historical paradigms and lateral thinking are also demonstrated by many papers, including Belaidi et al. (Lancaster), Goffey et al. (Bor Tuck and Lille John) and Catto et al. (Cygnus). Finally, the value of applying an integrated subsurface description extending from overburden to reservoir is clearly shown to create values in areas or reservoirs thought to be highly mature with little upside. Here, the Apache papers on Forties (Singer et al. 2017) and Beryl (Pyle et al. 2017) are good examples, together with the Rhyl paper by Ward & Baker (2016) and the paper by Stevenon & Bowman (2016) on the onshore Welton Field. All of these combine to give real hope that there is considerable remaining value to be realized in the region by radical thinking, high-quality technical work and challenging paradigms, as well as integration and new or novel technology application.

Plays and fairways

The papers in this group bring focus to areas that have proven lean in terms of commercial hydrocarbons discovered to date. They illustrate the variety of analyses and techniques used to better inform prospectivity from a number of new perspectives.

van Buchem et al. (2017) have written a seminal paper that not only describes the basin evolution but also establishes a new formal stratigraphic framework for the Cretaceous of the Danish Central Graben. Importantly, they document an Early Campanian unconformity within the Chalk which separates a lower, early post-rift thermal cooling period of basin formation and an upper interval defined by active inversion tectonics. They also discuss the relevance of this to Cretaceous prospectivity and plays.

In the UK sector, Green et al. (2017) use vitrinite reflectance (VR), apatite fission track analysis (AFTA) and sonic velocity data to document an earlier pre-Chalk uplift, as well as Palaeogene and Neogene uplifts of 1 km or more. They present burial curves and new maps of these uplifts which have may have significant consequences for hydrocarbon exploration, as do the ice age uplifts discussed by Goffey et al. (2016) (see below).

To the east of the Southern North Sea, the Entenschnabel or Duck’s Beak is an instantly recognizable feature in the outline of the German sector, which has not seen a lot of exploration success. In an effort to resolve the charge complexities, Arfai & Lutz (2017) have undertaken a comprehensive basin modelling exercise. This demonstrates, amongst other things, that the Step and Central Graben have substantially different heat flows associated with rifting. Details like this can be important in re-directing exploration.

The Triassic Skagerrak Formation of the Central North Sea is very thick and has a wide variety of facies. Undaunted, Akpokodje et al. (2017) examined 10 000 ft of core data from 86 cored wells to understand the main drivers of reservoir quality destruction with depth. They conclude that the predominant control on porosity loss is facies, with both mechanical compaction and early cementation being strongly facies-related. Early overpressure can prevent some porosity loss. They test their conclusions by forward modelling porosity loss at depth in a blind test for the best, fluvial, facies.

The Mid North Sea High is lightly explored but boasts two gas discoveries (Breagh and Crosgan) in Dinantian sandstones that indicate access of charge. Patruno et al. (2017) document a large Zechstein platform using seismic geometries, which could prove to be a large prospective reservoir body.

Dmitrieva et al. (2017) review the Palocene deep-water sands of the Norwegian North Viking Graben which are less well known than their UK cousins. They show how their deposition was influenced by tilted fault blocks which may have acted as sources, as well as constraining channel and fan geometries.

In an authoritative view of Irish exploration over the last 46 years, Shannon (2016) sees hope for the future based on a combination of new seismic data, better seismic imaging and new geological understanding both on the grand scale, such as hyper-extended continental margins, and the small scale, such as fault juxtapositions in the Celtic Sea basins.

Scotchman et al. (2016) review the results of 200 wells drilled along the NE Atlantic margin west of the British Isles (including Ireland) and conclude that a major control on hydrocarbon distribution is the patchy nature of the overwhelmingly most productive Upper Jurassic source rocks. This they attribute to localized depocentres in small sub-basins (productivity and dilution effects) and to subsequent hyper-extension during an Early Cretaceous rifting phase which further dispersed the Upper Jurassic source rocks.

The Porcupine Basin off Western Ireland appears as a target in both the preceding papers. Watremez et al. (2016) use travel-time tomography from two wide-angle seismic profiles to elucidate the crustal structure. They propose hyper-extension, with stretching factors (β) ranging from 6 to 10, and an igneous origin for the Porcupine Median Ridge.
**Fig. 1.** Summary geology of the North Sea and broader region illustrating the principal reservoir and source systems, and showing the range of papers covered in this volume (figure adapted from Underhill 2011). The paper numbers on the right-hand side (8.1, 8.38 etc.) are the final digits of the paper’s complete DOI. Click on these numbers to be directed to each paper.
Prospectivity along the Atlantic margin would be deemed greater if the industry could gain confidence in reservoirs within volcanic sequences. By studying analogues at outcrop in the Kangerlussuaq Basin of SE Greenland, Larsen et al. (2016) explain the occurrence and properties of interbedded siliciclastic reservoirs, such as those in the Rosebank field of the Faroe–Shetland Basin.

In a contribution that won the Peter Ziegler/David Roberts best paper award, Schofield et al. (2017) describe the current state of knowledge of the UK Rockall Trough west of Scotland where 12 wells have resulted in just one sub-commercial gas discovery. They highlight the opportunity to re-examine the basin with a better understanding of the detailed impact of its volcanic history – for example, understanding exactly how thick the Cretaceous sediments are by subtracting the sills, and the downsides of testing forced-folds producing four-way dip closures but directly above impermeable sills.

The Voring Basin has been tantalizing explorers for decades now, with a number of sub-commercial gas 'discoveries'. One of the reasons may be poor reservoir quality. This is addressed by Finlayson et al. (2017). They identify a clear facies control on porosity and permeability in the Campanian–Maastrichtian Springar Formation turbidites rather than simply being controlled by compaction trends.

**Play assessment**

Allocating capital to projects efficiently relies on a correct assessment of volumes and risks. This is something that explorers have to work hard at to achieve and even harder to sustain. This group of papers addresses the issues involved in unbiased play and prospect evaluation.

Citron et al. (2016) explain, with very clear examples, the role in play and prospect risking of combining backward-looking analysis with structured forward-looking risking using appropriately chosen calibration datasets. They show how this approach allows a risking system to be tuned by identifying the key risk failures, and progress measured on both risking of success and estimation of volumes.

Mathieu (2016) provides a backward-looking review of nearly 100 wells drilled in the Moray Firth and Central North Sea in terms of actual v. predicted outcomes. The paper demonstrates that both success and volumes were systematically overestimated. A key finding is that nearly 40% failed for multiple reasons. In other words, these were very probably avoidable dry holes. A high number (55%) of the tested traps were stratigraphic, and lateral seal failure was a main reason for these failures.

Stratigraphic traps, or, perhaps, more accurately traps with a large stratigraphic component to closure, cause more emotion...
(both joy and sorrow) than most. They are often found in a second
wave of exploration, in acreage that has been relinquished, some-
times more than once. Frequently, opportunities to participate
have been declined. A structured approach to risking the elements
of stratigraphic closures is to be welcomed and Stirling et al.
(2017) provides an eminently practical approach by sharing the
risking practices used in BP.

Recent successes and learnings from failures
Case histories of field discovery or field development are often
among the best sessions at conferences and so it proved at this
event, with an inspiring set of papers detailing, in most cases,
how persistence and fresh thinking had turned non-commercial
finds into fields.

In a well-crafted paper, Goffey et al. (2016) describe two 2011
discoveries in the Danish Central Graben – Brør Tuck (gas) and
Lille John (oil) – both of which are close to wells with minor
hydrocarbon discoveries drilled between 1975 and 1985. Forensic
examination of the drilling history of these early wells together
with an openness to new structural models in combination with relat-
ing deposition to structural evolution are behind these discoveries.
Lille John has wide significance in demonstrating the likely recent
remigration of undegraded light oils into shallow traps due to the
effects of stressing and de-stressing by ice through glacial cycles.

Cygnus in the Southern North Sea is yet another discovery based
on re-analysis of shows. Catto et al. (2017) document how a disap-
pointing 1988 well with gas shows in Leman sandstones on the
‘northern feather edge of the Leman play’ has now been supple-
mented by a subcropping Lower Ketch reservoir. They demonstrate
that the Leman reservoir is locally derived from the north and is,
therefore, thicker than expected. In summary, this lead to the
third largest gas field discovered in the Southern North Sea in the
last 30 years.

The case study of the Bacchus Field by Rose et al. (2016a) cov-
ers a small high-pressure–high-temperature (HPHT) field in the
Central North Sea near Forties. Discovered in 2004, the paper
demonstrates in detail that flexibility in development in the face
of unresolved uncertainty may offer the best approach to fields at
the limit of geophysical and geological resolution, and where the
risked volumes do not support further appraisal drilling and data
acquisition.

The description of the Skarfjell discovery by Koch et al. (2017)
provides a fine example of a stratigraphically trapped accumulation
sealed laterally by mudstone-filled incised channels, and updip by
subcrop. It demonstrates, yet again, that once a prolific kitchen
has been identified there are many subtle traps that need to be
explored for using detailed and careful seismic mapping combined
with a good stratigraphic understanding.

The Rhyl gas field in the Irish Sea (Ward & Baker 2016) was
hidden from the industry until 2009 by virtue of overburden
velocity anomalies due to glacial sediment, dykes and structural
complexities. The authors describe how integrated subsurface anal-
ysis, notably the combination of careful geophysical analyses and
structural understanding, led to the field’s discovery 33 years
after its near neighbour, the Morecombe Field.

The sandstone reservoirs at Rosebank Field in the Flett sub-
basin, West of Shetland, were deposited where a northerly prograd-
ing Palaeogene delta met an easterly prograding field of lava flows.
Poppitt et al. (2016) explain how seismic recorded by ocean bot-
tom nodes (OBN)s has been used for better imaging: Spectral anal-
ysis helped resolve volcanic facies and a combination of acoustic
and elastic inversion to resolve the siliciclastic facies. Further
refinement of the reservoir model was achieved using analogue
studies such as those described elsewhere in this volume by Larsen
et al. (2016).

The final paper in this group demonstrates the merit of deter-
mination and not giving up in unlocking a perceived high risk play.
This is the fractured basement (Lewisian gneiss) play that is the
Lancaster discovery on the Rona Ridge West of Shetland (Belaidi
et al. 2016). Here, appraisal well results give hope to this being a
successful example of what is globally a challenging play type.

Infrastructure-led exploration and development
The five papers grouped under this theme offer a balanced view of
what has been one of the focus areas for petroleum geoscience in an
increasingly mature province. The learnings from high-quality and
focused application of technology show how near-field and upside
potential could be realized in the Central North Sea Huntington
(Green et al. 2016; Edwards et al. 2017) and Shearwater fields
(Jones et al. 2017).

Both show the benefits of continuing forensic geoscience in field
development and production.

Huntington is not exactly a new field (discovered in 2007) but
Edwards et al. (2017) provide a clear and careful sedimentological
description of the reservoir highlighting the paradox of a systemati-
cally lateral accreting seismic geometry apparently associated with
a system of straight rather than sinuous channels. Illustrating that
with deep-water clastic deposits what you see is what you get rather
than what you are led to expect by models.

Total’s advantageous use of infrastructure to extend facility life
is shown in the paper by Noel & Taylor (2016), which demon-
strates how near-field exploration has extended the Laggan–
Tormore gas-condensate development. A similar approach is
described by Skarpeid et al. (2017), who describe how the life of
the Knorre Field in the Norwegian sector has been extended by
the development of the deeper Cook Formation reservoir.

Late-life fields, redevelopment and the next life
These papers offer a number of high-quality examples of how judi-
cious use of technology can realize value in mature, late-life fields.
The dominance of Apache in the author’s list reflects the recog-
nized competency that this company has developed in field rejuve-
nation and redevelopment. The application of high-resolution
seismic in the Forties Field reservoir and the use of shallow gas
(Aviation) to deliver a local supply of fuel gas to the Forties infrastruc-
ture are elegantly captured in the papers by Singer et al. (2017) and
Rose et al. (2016b), respectively. They are complemented by
Wright et al.’s (2017) clear description of how spectral decomposi-
tion has helped define reservoir architecture in the Laggan–
Tormore Field, West of Shetlands, and Brain et al.’s (2017) study of
the continuing refinement of seismic technology in the Southern
North sea Rotliegend play. The final paper in this compilation is
by Pyle et al. (2017) on the Beryl Field; it is another excellent dem-
onstration of Apache’s deep competency in breathing new life into
a mature and declining asset. The papers each clearly demonstrate
that a field’s productivity and potential can be re-energized by
application of integrated high-quality subsurface techniques and
mature field focused work flows.

The other papers in this session reflect how industry is adopting
new tools and approaches to create and deliver the next cycle of
value to the region. Gluyas et al.’s (2016) keynote broadens the dis-
cussion to look at the potential response to the environmental chal-
enges confronting the industry with discussion of future options
and opportunities. Marshall et al. (2017) offer an elegant de-
scription of the Goldenoeye Carbon Capture and Storage (CCS) pro-
ject that was planned to revitalize this former gas-condensate
reservoir in the Moray Firth (funding for the CCS competition
was withdrawn shortly after the conference). Both papers
demonstrate clearly that there is remaining value in mature and

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depleted reservoirs but unconventional thinking and incentivized approaches are needed.

The paper by Bentley & Ringrose (2017) on future directions in reservoir modelling fits well with mature field thinking. It talks to how new and more informed techniques and approaches can enhance the value and impact of modelling techniques for reservoir rate and performance prediction. They particularly emphasize the need for integrating newest technology (algorithms, gridding, workflows) with uncertainty and risk-based thinking. Together, this section of papers offers a good overview of the challenges and opportunities offered in a mature basin where technology has been an enduring key to success and value creation, from the early days of exploration and appraisal to late-life fields and reservoirs.

**Onshore exploration and development**

The papers covering the onshore activities in the region reflect the balance of current interest and focus with unconventional resources dominating. Harvey et al.'s (2016) keynote on shale reservoir potential offers the latest insights from the British Geological Survey (BGS) into their characteristics, scale, distribution and prospectivity. The natural focus on the Bowland Shales in NW England reflects their potential but the work also brings focus to other plays that have seen some early success, such as the Kimeridge Clay in southern England.

The paper by Riley et al. (2016) describes some of the different technologies being used to enhance how the industry characterizes the uncertainties associated with different shale plays together with the associated exploration-related risks. It is becoming clear that integrated multidisciplinary approaches offer the best chance of success in these onshore plays where combining the various technologies and techniques used in conventional resource assessment with high-resolution mudrock-focused techniques can help better characterize and predict the location and distribution of high-quality resources (sweet spots). Clearly, a range of geochemical fingerprinting will be a key part of this and Riley et al.'s (2016) paper reflects one such approach. The paper by Hughes et al. (2016) (a winner of the Peter Ziegler/Dave Roberts best paper award) on the mid-1980s Kirby Misperton gas field in North Yorkshire reflects the unconventional upside potential in a deeper Bowland Shale play below the original Namurian and Zechstein reservoirs that are now relatively depleted.

The final paper on the onshore petroleum systems is the only one to focus on the conventional resources that have been the focus for onshore exploration and development in past years. This very much reflects the maturity of the basin for conventional resources with the few fields remaining on production and most of these in late life decline. The paper by Steventon & Bowman (2016) demonstrates how the integration of a traditional reservoir description with production information can identify upside potential and opportunities in a mature field. The Huntington Field is the largest discovered in the East Midlands Carboniferous province; the paper describes the remaining potential in the secondary Upper Carboniferous reservoirs across the field.

**References**


