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

BRUCE LEVELL[1]* and MIKE BOWMAN[2]

[1]*Department of Earth Sciences, University of Oxford, South Parks Road, Oxford OX1 3AN, UK*
[2]*Texas A&M University at Qatar, Education City, Doha, Qatar*

**Correspondence:* *brucel@earth.ox.ac.uk*

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*

Stratigraphic age	Reservoir/field		Region
Eocene	Catcher	28/9a-6 28/9a-2	UKCS Northern North Sea
Eocene	Intra-volcanic sands	Outcrop samples	
Eocene	Schiehallion	204/20-1	West of Shetlands
Paleocene	Nelson	22/11-N1 22/11-N9 21/11-N16Y	UKCS Central North Sea
Cretaceous	Goldeneye	14/29a-3	UKCS Moray Firth
Cretaceous	Buzzard	4B 20/01-8 4C 20/06-4	UKCS Moray Firth
Cretaceous	Ettrick	20/02a-E5	UKCS Moray Firth
Jurassic	Harelv Formation	Blokelv-1	Greenland Outcrops
Jurassic	Magnus	211/ 12a-M16	UKCS Northern North Sea
Jurassic	Shearwater	22/30b-11 22/30b-A6	UKCS Central North Sea
Jurassic	Brent	211/29-C4	UKCS Northern North Sea
Permian	Cygnus	44/12a-4	UKCS Southern North Sea
Carboniferous	Cygnus	44/12a-3	UKCS Southern North Sea
Carboniferous	Welton	Welton A14 Welton B09	UK Onshore
Carboniferous	Wingate	D15-FA-101x 44/24b-7 44/24b-A4	UKCS Southern North Sea
Devonian	Clair	206/8-11A 206/8-A02	West of Shetlands

From: BOWMAN, M. & LEVELL, B. (eds) 2018. *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*, 1–8.
First published online September 25, 2017, https://doi.org/10.1144/PGC8.41

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 (**Steventon & 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.* (2016)** (Lancaster), **Goffey *et al.* (2016)** (Bror Tuck and Lille John) and **Catto *et al.* (2017)** (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 **Steventon & 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 Skaggerak 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 Paleocene 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.

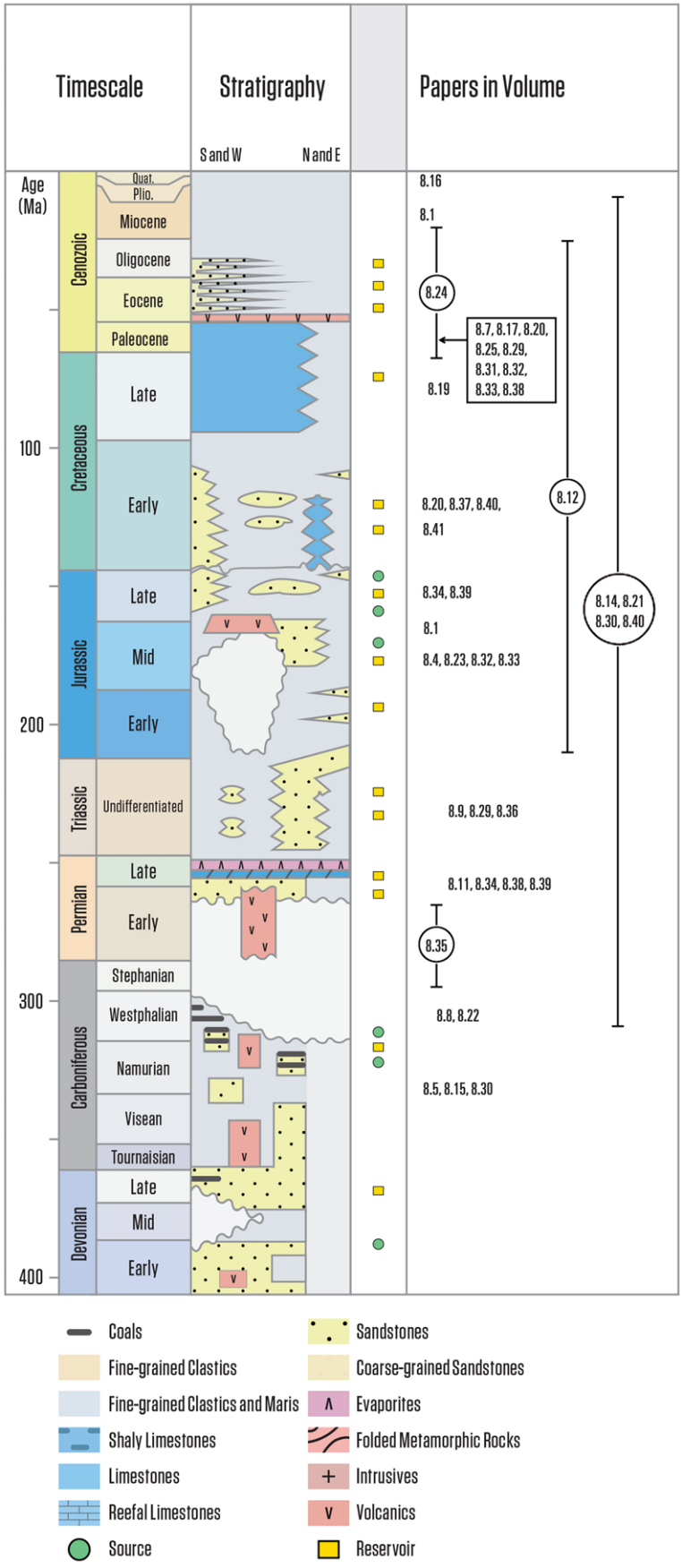

Fig. 1. Summary geology of the North Sea and broader region illustrating the principal reservoir and source systems, and showing the range of papers covered in this volume (figure adapted from Underhill 2011). The paper numbers on the right-hand side (8.1, 8.38 etc.) are the final digits of the paper's complete DOI. Click on these numbers to be directed to each paper.

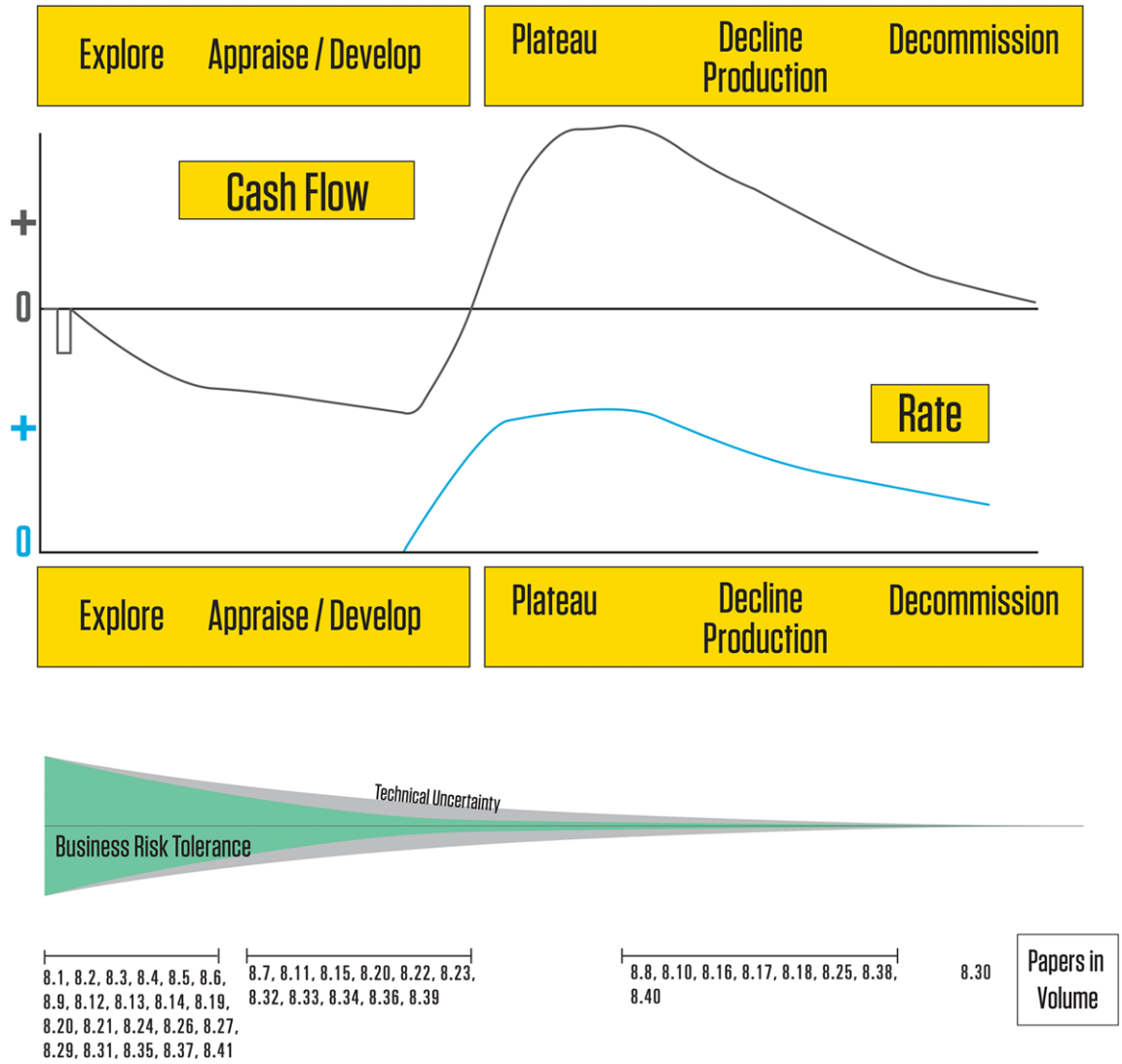

Fig. 2. Summary diagram of the Upstream Exploration and Production Value Chain illustrating the range of uncertainty and value creation from access to cessation of production and showing the range of papers covered in this volume. The paper numbers in the bottom line (8.1, 8.38 etc.) are the final digits 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 buy subtracting the sills, and the down sides 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, sometimes 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 – Bror 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 relating 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 disappointing 1988 well with gas shows in Leman sandstones on the 'northern feather edge of the Leman play' has now been supplemented 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.* (2016*a*)** covers 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 acquistion.

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 analysis, 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 subbasin, West of Shetland, were deposited where a northerly prograding Palaeogene delta met an easterly prograding field of lava flows. **Poppitt *et al.* (2016)** explain how seismic recorded by ocean bottom nodes (OBNs) has been used for better imaging. Spectral analysis 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 grouping demonstrates the merit of determination 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 systematically 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 demonstrates 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 judicious use of technology can realize value in mature, late-life fields. The dominance of Apache in the author's list reflects the recognized competency that this company has developed in field rejuvenation and redevelopment. The application of high-resolution seismic in the Forties Field reservoir and the use of shallow gas (Aviat) to deliver a local supply of fuel gas to the Forties infrastructure are elegantly captured in the papers by **Singer *et al.* (2017)** and **Rose *et al.* (2016*b*)**, respectively. They are complemented by **Wright *et al.*'s (2017)** clear description of how spectral decomposition 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 demonstration 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 discussion to look at the potential response to the environmental challenges confronting the industry with discussion of future options and opportunities. **Marshall *et al.* (2017)** offer an elegant description of the Goldeneye Carbon Capture and Storage (CCS) project 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

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 Kimmeridge 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 Welton 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

Akpokodje, M., Melvin, A. *et al*. 2017. Regional study of controls on reservoir quality in the Triassic Skagerrak Formation of the Central North Sea. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 23 June 2017, https://doi.org/10.1144/PGC8.29

Arfai, J. & Lutz, R. 2017. 3D basin and petroleum system modelling of the NW German North Sea (Entenschnabel). *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 17 March 2017, https://doi.org/10.1144/PGC8.35

Belaidi, A., Bonter, D.A., Slightam, C. & Trice, R.C. 2016. The Lancaster Field: progress in opening the UK's fractured basement play. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 26 September 2016, https://doi.org/10.1144/PGC8.20

Bentley, M. & Ringrose, P. 2017. Future directions in reservoir modelling: new tools and 'fit-for-purpose' workflows. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 30 May 2017, https://doi.org/10.1144/PGC8.40

Brain, J., Lassaigne, T., Darnet, M. & Van Loevezijn, P. 2017. Unlocking 4D seismic technology to maximize recovery from the pre-salt Rotliegend gas fields of the Southern North Sea. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 3 July 2017, https://doi.org/10.1144/PGC8.38

Catto, R., Taggart, S. & Poole, G. 2017. Petroleum geology of the Cygnus gas field, UK North Sea: from discovery to development. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 23 March 2017, https://doi.org/10.1144/PGC8.39

Citron, G.P., Brown, P.J., MacKay, J., Carragher, P. & Cook, D. 2016. The challenge of unbiased application of risk analysis towards future profitable exploration. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 27 October 2016, https://doi.org/10.1144/PGC8.2

Dmitrieva, E., Jackson, C.A.-L., Huuse, M. & Kane, I.A. 2017. Regional distribution and controls on the development of post-rift turbidite systems: insights from the Paleocene of the eastern North Viking Graben, offshore Norway. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 30 May 2017, https://doi.org/10.1144/PGC8.31

Edwards, C., McQuaid, S., Easton, S., Scott, D., Couch, A., Evans, R. & Hart, S. 2017. Lateral accretion in a straight slope channel system: an example from the Forties Sandstone of the Huntington Field, UK Central North Sea. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 16 January 2017, https://doi.org/10.1144/PGC8.33

Finlayson, A., Melvin, A., Guise, A. & Churchill, J. 2017. Controls on the reservoir quality of Late Cretaceous Springar Formation deep-water fan systems in the Vøring Basin. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 13 June 2017, https://doi.org/10.1144/PGC8.27

Gluyas, J., Mathias, S. & Goudarzi, S. 2016. North Sea – next life: extending the commercial life of producing North Sea fields. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 27 October 2016, https://doi.org/10.1144/PGC8.30

Goffey, G., Attree, M. *et al*. 2016. New exploration discoveries in a mature basin: offshore Denmark. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings*

of the 8th Petroleum Geology Conference. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 26 September 2016, https://doi.org/10.1144/PGC8.1

Green, P.F., Duddy, I.R. & Japsen, P. 2017. Multiple episodes of regional exhumation and inversion identified in the UK Southern North Sea based on integration of palaeothermal and palaeoburial indicators. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 17 March 2017, https://doi.org/10.1144/PGC8.21

Green, S., O'Connor, S., Swarbrick, R. & Waters, K. 2016. A hydrodynamic model and associated spill-point map for the Huntington Field, UK Central North Sea. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 29 November 2016, https://doi.org/10.1144/PGC8.7

Harvey, A.L., Andrews, I.J. & Monaghan, A.A. 2016. Shale prospectivity onshore Britain. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 15 December 2016, https://doi.org/10.1144/PGC8.15

Hughes, F., Harrison, D. *et al*. 2016. The unconventional Carboniferous reservoirs of the Greater Kirby Misperton gas field and their potential: North Yorkshire's sleeping giant. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 26 September 2016, https://doi.org/10.1144/PGC8.5

Jones, D.W., Taylor, B.J. *et al*. 2017. The Shearwater Field – understanding the overburden above a geologically complex and pressure-depleted high-pressure and high-temperature field. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 3 July 2017, https://doi.org/10.1144/PGC8.36

Koch, J.-O., Frischbutter, A., Øygard, K. & Cater, J. 2017. The 35/9-7 Skarfjell discovery: a genuine stratigraphic trap, NE North Sea, Norway. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 17 March 2017, https://doi.org/10.1144/PGC8.34

Larsen, M., Bell, B., Guarnieri, P., Vosgerau, H. & Weibel, R. 2016. Exploration challenges along the North Atlantic volcanic margins: the intra-volcanic sandstone play in subsurface and outcrop. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 27 October 2016, https://doi.org/10.1144/PGC8.13

Marshall, J.D., Tucker, O.D., Lovelock, C.E., Darker, S.J., Annia, C.E. & Hognestad, J.B. 2017. Goldeneye: Tomorrow Never Dies (or a field Only Lives Twice). *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 30 January 2017, https://doi.org/10.1144/PGC8.18

Mathieu, C.J.H. 2016. Exploration well failures from the UK North Sea. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 26 September 2016, https://doi.org/10.1144/PGC8.3

Noel, P. & Taylor, N. 2016. Beyond Laggan–Tormore: maximizing economic recovery from gas infrastructure West of Shetland. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 26 September 2016, https://doi.org/10.1144/PGC8.17

Patruno, S., Reid, W., Jackson, C.A.-L. & Davies, C. 2017. New insights into the unexploited reservoir potential of the Mid North Sea High (UKCS quadrants 35–38 and 41–43): a newly described intra-Zechstein sulphate–carbonate platform complex. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 13 June 2017, https://doi.org/10.1144/PGC8.9

Poppitt, S., Duncan, L.J., Preu, B., Fazzari, F. & Archer, J. 2016. The influence of volcanic rocks on the characterization of Rosebank Field – new insights from ocean-bottom seismic data and geological analogues integrated through interpretation and modelling. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 15 December 2016, https://doi.org/10.1144/PGC8.6

Pyle, J., Farquharson, G., Gibson, J., Helgeson, D. & Towart, J. 2017. The Beryl Field area: increasing production in a mature asset. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online August 30, 2017, https://doi.org/10.1144/PGC8.32

Riley, D.A., Pearce, T.J., Mathia, E., Ratcliffe, K. & Martin, J. 2016. The application of elemental geochemistry to UK onshore unconventional plays. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 26 September 2016, https://doi.org/10.1144/PGC8.8

Rose, P., Byerley, G. & Vaughan, O. 2016*a*. The Bacchus development: dealing with geological uncertainty in a small high-pressure–high-temperature development. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 26 September 2016, https://doi.org/10.1144/PGC8.4

Rose, P., Byerley, G., Vaughan, O., Cater, J., Rea, B.R., Spagnolo, M. & Archer, S. 2016*b*. Aviat: a Lower Pleistocene shallow gas hazard developed as a fuel gas supply for the Forties Field. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 27 October 2016, https://doi.org/10.1144/PGC8.16

Schofield, N., Jolley, D. *et al*. 2017. Challenges of future exploration within the UK Rockall Basin. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 16 February 2017, https://doi.org/10.1144/PGC8.37

Scotchman, I.C., Doré, A.G. & Spencer, A.M. 2016. Petroleum systems and results of exploration on the Atlantic margins of the UK, Faroes & Ireland: what have we learnt? *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 27 October 2016, https://doi.org/10.1144/PGC8.14

Shannon, P.M. 2016. Old challenges, new developments and new plays in Irish offshore exploration. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 15 December 2016, https://doi.org/10.1144/PGC8.12

Singer, L., Byerley, G. & Rose, P. 2017. Re-saturation targets identified from 4D seismic softening responses in the Forties Field. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series,

8. First published online 16 January 2017, https://doi.org/10.1144/PGC8.25

Skarpeid, S.S., Churchill, J.M., Hilton, J.P.J., Izatt, C.N. & Poole, M.T. 2017. The Knarr Field: a new development at the northern edge of the North Sea. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 3 February 2017, https://doi.org/10.1144/PGC8.23

Steventon, J. & Bowman, M. 2016. An assessment of the Upper Succession and the related secondary reservoirs in the Welton Field, onshore UK. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 15 December 2016, https://doi.org/10.1144/PGC8.22

Stirling, E.J., Fugelli, E.M.G. & Thompson, M. 2017. The edges of the wedges: a systematic approach to trap definition and risking for stratigraphic, combination and sub-unconformity traps. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 3 February 2017, https://doi.org/10.1144/PGC8.19

Underhill, J. 2011. Structural evolution of the North Sea petroleum system. *In*: *North Sea Petroleum Geology PESGB/Nautilus Short Course: E&P Strategies in a Mature Hydrocarbon Province*. Petroleum Exploration Society of Great Britain (PESGB), London.

van Buchem, F.S.P., Smit, F.W.H., Buijs, G.J.A., Trudgill, B. & Larsen, P.-H. 2017. Tectonostratigraphic framework and depositional history of the Cretaceous–Danian succession of the Danish Central Graben (North Sea) – new light on a mature area. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 16 January 2017, https://doi.org/10.1144/PGC8.24

Ward, G. & Baker, D. 2016. Rhyl Field: developing a new structural model by integrating basic geological principles with advanced seismic imaging in the Irish Sea. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 27 October 2016, https://doi.org/10.1144/PGC8.11

Watremez, L., Prada, M. *et al*. 2016. Deep structure of the Porcupine Basin from wide-angle seismic data. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 27 October 2016, https://doi.org/10.1144/PGC8.26

Winter, D.A. & King, B. 1991. The West Sole Field, Block 48/6, UK North Sea. *In*: Abbotts, I.L. (ed.) *United Kingdom Oil and Gas Fields, 25 Years Commemorative Volume*. Geological Society, London, Memoirs, **14**, 517–523, https://doi.org/10.1144/GSL.MEM.1991.014.01.65

Wright, K.A., Nice, R., Tazzi, M., Purnell, K. & Penasse, V. 2017. Spectral decomposition: an aid in characterizing field architectures of the Laggan and Tormore fields, Faroe–Shetland Basin. *In*: Bowman, M. & Levell, B. (eds) *Petroleum Geology of NW Europe: 50 Years of Learning – Proceedings of the 8th Petroleum Geology Conference*. Geological Society, London, Petroleum Geology Conference series, **8**. First published online 17 March 2017, https://doi.org/10.1144/PGC8.10