Institution: The University of Edinburgh

Unit of Assessment: B7 – Earth Systems and Environmental Sciences

Title of case study: ECONOMIC BENEFITS DERIVED FROM EXPLOITATION OF NORTH SEA OIL AND GAS FIELDS

1. Summary of the impact

Impact: Economic benefits arising from new exploitations of North Sea oil and gas fields (2008 – June 2013), including oil production at the Bentley field by Xcite Energy Ltd and gas production at the Wissey field by Tullow Oil plc.

Significance and reach: The Bentley field produced 47,000 barrels of oil (value ~$4.7M) over the period 2011 – 2012, with an estimated ~900M barrels in place. [text removed for publication].

Underpinned by: Research into the identification of geological features through seismic and sequence stratigraphy, undertaken at the University of Edinburgh (1993 – June 2013).

2. Underpinning research

Numbered references refer to research outputs in Section 3.

Key researchers

The start and end dates of continuous employment in the School of GeoSciences, University of Edinburgh, are shown along with the most recent / current position of each researcher.

Underhill, Professor (1993 – June 2013)
Dawers, Sharp and Gupta were all PDRAs at intervals during the period 1993 – 2012

Research overview and context

Over the period 1993 – June 2013, Underhill led a group at Edinburgh engaged in fundamental and applied research in seismic and sequence stratigraphy. This involved analysis and joint interpretation of well-calibrated analogue and digital geophysical and geological data to establish correlations in seismic and well data relating to stratigraphic boundaries and to elucidate the sedimentary and structural processes involved, the latter also being informed by studies of outcrop from onshore analogues. This body of research has been conducted in close collaboration with industry, including two sabbatical periods for Underhill (one at BP and the other in Norsk Hydro's Bergen research facility) during which the research findings were used to specifically advance understanding and correlation of North Sea reservoirs.

Key research findings that underpin the subsequent impact

The fundamental tools used to establish the stratigraphic correlations between North Sea reservoirs were developed in the 1990s (e.g. *Partington et al., 1993*). This stratigraphic framework formed the basis by which the development and evolution of the North Sea could be deduced, and elucidated the gross depositional environment palaeo-geographies and reservoir play 'fairways' that underpin successful exploration in the North Sea Jurassic to this day. A major discovery underlying this approach was that the North Sea basin and its associated volcanism resulted from North Sea doming, rather than the product of rifting, as first described in a 1993 study published by Underhill **[1]**. This work made use of a major methodological innovation, the extension of previous analysis of clastic sand bodies (the reservoir rocks) to shales, which enabled the identification of a new type of stratigraphic horizon in the form of marine condensed horizons **[1]**. Such 'maximum flooding events' are useful as correlative tools and also in calibrating sea level changes through geological time. The use of such features has been important in demonstrating the role of fault growth and propagation in the North Sea and similar rift systems, as described in 1997 - 2000 publications by the group **[2,3]**.

Applied research on the North Sea published by Underhill in 2001 identified a four-way dip closure

of the Lower Eocene and Upper Palaeocene Dornoch sandstone reservoir, resulting from doming associated with the initial pulse in the development of the Iceland plume **[4]**, a structure now known as the Bentley oilfield. Further applied work published by the group in 2009-2010 demonstrated I) the 'Fizzy' gas field to be a safe, proven site for carbon storage **[5]**, and II) the previously unrealised commercial potential of the 'Scram' gas field (now known as the Wissey gas field) **[6]**. This latter work combined geophysical attribute analysis derived from dip azimuths and coherency obtained through 3D seismic mapping with geological ground-truthing.

3. References to the research

Comments in bold on individual outputs give information on the quality of the underpinning research and may include the number of citations (Scopus, up to September 2013 unless otherwise stated) and/or the 2012 Thomson Reuters Journal Impact Factor (JIF). The starred outputs best indicate this quality.

[1]* Peer-reviewed book chapter, >210 citations on Google Scholar, up to September 2013
Underhill, J.R. and Partington, M.A. (1993) 'Jurassic thermal doming and deflation: implications of the sequence stratigraphic evidence', in: Parker, J.R. (Ed.): *Petroleum Geology of North-West Europe: Proceedings of the 4th Conference*, 337-345, DOI: 10.1144/0040337

[2]* Peer-reviewed journal article, 70 citations
Dawers, N.H. and Underhill J.R. (2000) 'The Role of Fault Interaction and Linkage in Controlling Syn-Rift Stratigraphic Sequences: Statfjord East area, Northern North Sea', *American Association of Petroleum Geologists Bulletin*, 84, 45-64,
DOI: 10.1306/C9EBCD5B-1735-11D7-8645000102C1865D

[3] Peer-reviewed journal article, >140 citations, JIF: 4.1
Gawthorpe, R.L., Sharp, I., Underhill, J.R. and Gupta, S. (1997) 'Linked sequence stratigraphic and structural evolution of propagating normal faults', *Geology*, 25, 795-798,
DOI: 10.1130/0091-7613(1997)025<0795:LSSASE>2.3.CO;2

[4]* Peer-reviewed journal article illustrating the applied research, >10 citations, JIF: 2.1
Underhill, J.R. (2001) 'Controls on the genesis and prospectivity of Paleogene palaeogeomorphic traps, East Shetland Platform, UK North Sea', *Marine & Petroleum Geology*, 18, 259-281,
DOI: 10.1130/0091-7613(1997)025<0795:LSSASE>2.3.CO;2

[5] Peer-reviewed journal article
Underhill, J.R., Lykakis, N and Shafique, S. (2009) 'Turning exploration risk into a carbon storage opportunity in the UK Southern North Sea', *Petroleum Geoscience*, 15, 291-304,
DOI: 10.1144/1354-079309-839

[6] Peer-reviewed journal article (Duguid was an MRes student at Edinburgh, 2009 - 2010)
Duguid, C. and Underhill, J.R. (2010) 'Geological Controls on Upper Permian Plattendolomite Formation reservoir propsectivity, Wissey Field, UK Southern North Sea', *Petroleum Geoscience*, 16, 331-348, DOI: 10.1144/1354-0793/10-021

These outputs have been produced through several industry grants involving Underhill, including:

- [text removed for publication]
- [text removed for publication]
- [text removed for publication]

4. Details of the impact

Lettered references relate to corroboration sources in Section 5. All monetary calculations are based on current worth of the asset and an oil price of $100 per barrel.

Economic benefits from the exploitation of North Sea oil and gas fields (Primary Impact)

Pathway: The fundamental and applied research on industry data sets, often undertaken closely with the sponsor companies, has provided case histories that have had a direct impact upon commercial decision makers in multi-national companies operating in the North Sea. Three such examples are given here:

- Applied research by Underhill (encapsulated in output [4], Section 3) demonstrated the viability of, and formed the basis for, a successful bid in 2003 by Xcite Energy Ltd (UK) to produce the Bentley oil Field. That this bid was underpinned by the Edinburgh research can be confirmed by the Chief Operating Officer **[A]**. The first well was drilled in December 2007 – January 2008 and since then Xcite has continued to develop the site. The most recent drilling programme, pre-production wells 9/3b-7 and 7Z (cost ~£10 million each), began in 2011 and concluded in September 2012, having flowed for 68 days, demonstrating that the viscous and heavy oil is movable, as described on the Xcite website **[B]**.
- The Scram Discovery was first made in the Southern North Sea in 1967 but lay dormant primarily because the Upper Permian Zechstein Group carbonate reservoir was considered anomalous. The applied research by Underhill's group (encapsulated in output [6], Section 3) led directly to Tullow Oil plc (Rep. Ireland) investigating (2007 onwards) the viability of developing the discovery, as can be corroborated by the then Southern North Sea Exploration manager **[C]**. High flow rates resulted from the optimal exploitation of newly interpreted fracture networks derived from 3D seismic methods and this led to Tullow bringing the field – now rechristened the Wissey gas field - on stream in August 2008 **[D]**.
- The discovery of carbon dioxide in UKCS license block 49/30 was initially treated as an exploration failure, christened Fizzy because of its gas composition. The discovery lay dormant, passing from one operator to another until it was eventually relinquished by Tullow in 2008. However, Tullow acted on the implications of Underhill's research (encapsulated in output [5], Section 3) that such sites could act as carbon storage opportunities and successfully re-applied for the block in the recent 27th licensing round (October 2012) **[C,E]**.

Significance and reach:

- Independent trade sources confirm that over the period 2011 - 2012 47,000 barrels of oil (value ~$4.7M) were produced at the Bentley Oil Field **[F]**. The field is now estimated to contain some 900M barrels of oil in-place, as stated in Xcite reports **[B,G]**. Xcite have confirmed that the *"Net Present Value after tax for Bentley Field is $2.2billion on a 2P basis"* **[G]**. The field continues to be developed by Xcite, including acquisition of licenses over Blocks 9/4, 9/9f, 9/8b in the UK 27th Offshore Licensing Round (October 2012) **[E].**
- [text removed for publication].

Training of industry-based practitioners (Secondary Impact)

Pathway, significance and reach: The concepts of maximum flooding surfaces are now widely used by oil and gas company geologists in a wide range of tectonic and stratigraphic settings across the world. Training in these research-derived methods occurs through both badged courses and consultancy work. The Petroleum Exploration Society of Great Britain (PESGB) run an industry-based course on an 18-month cycle, including 5 times over the period 2008 - 2013, with a total of 475 oil company employee attendees over that time **[H]**. Other professional societies that have run badged courses and workshops include the European Association of Geoscientists and Engineers (EAGE), Geological Society of London, and the American Association of Petroleum Geologists (AAPG), who recognised the value of Underhill's contribution to geological training by their Murray Distinguished Educator Award in May 2013 **[I]**.

5. Sources to corroborate the impact
Where two web-links are given, the first is the primary source and the second an archived version.

[A] Chief Operating Officer, Xcite Energy (UK)
Can provide corroboration that Underhill's research work led to his company seeking a license for the fallow 9/3 discovery that subsequently led to the development of the Bentley Field.

[B] Xcite Energy web-pages on business performance measures for the Bentley Oil Field
http://tinyurl.com/B7-9-S5-XB1 or http://tinyurl.com/B7-9-S5-B
Provides corroboration of the 2011-2012 drilling programme at Bentley and associated production figures, as well as the estimated total reserves.

[C] Former Southern North Sea Exploration manager, Tullow Oil plc (Ireland)
Can provide corroboration that: I) Underhill's research work led directly to the application to exploit the Wissey gas field, II) Underhill's research work was fundamental in supporting the company's successful re-application for the Fizzy Field license as a carbon storage site, and III) [text removed for publication].

[D] Tullow Oil plc half-yearly report 2008
http://tinyurl.com/B7-9-S5-XD or http://tinyurl.com/B7-9-S5-D
Provides corroboration of business performance measures, including the first production of gas at the Wissey Field in August 2008 and the associated rate (Page 2).

[E] Table of license awards from UK 27th licensing round, announced October 2012
http://tinyurl.com/B7-9-S5-XE or http://tinyurl.com/B7-9-S5-E
Corroborates the stated license acquisitions for: I) Xcite Energy for the Bentley Field (Page 8), and II) Tullow Oil for the 'Fizzy' discovery (Page 8).

[F] Offshore.no article on business performance measures for the Bentley Oil Field, August 2012 http://tinyurl.com/B7-9-S5-XF1 or http://tinyurl.com/B7-9-S5-F
Provides independent confirmation of the number of wells drilled and barrels produced in the 2011-2012 drilling programme at Bentley.

[G] Xcite Energy Reserves Assessment on the Bentley Field, April 2013
http://tinyurl.com/B7-9-S5-XG1 or http://tinyurl.com/B7-9-S5-G1
Corroborates the estimated total barrels of oil in place at Bentley and the quoted statement regarding the estimated P2 value of the field, both important business performance measures.

[H] PESGB North Sea Petroleum Geology Course (November 2013 iteration) website
http://tinyurl.com/B7-9-S5-XH1 or http://tinyurl.com/B7-9-S5-H
Provides evidence of the co-ordinating role of Underhill in this 'regular' research-driven training course, representing sustained engagement with the training of industry professionals.

[I] AAPG Murray Distinguished Educator Award (May 2013)
http://tinyurl.com/B7-9-S5-XI1 or http://tinyurl.com/B7-9-S5-I1
Corroborates the award made to Underhill in 2013, for his work to improve engagement with science both within and outside of HEIs.