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.

Institution: The University of Edinburgh

Unit of Assessment: B7 – Earth Systems and Environmental Sciences

Title of case study: ECONOMIC BENEFITS DERIVED FROM MTEM LIMITED

1. Summary of the impact

Impact: Economic benefits have been derived from the MTEM Limited spin-out company, which has been owned since 2007 by Petroleum Geo-Services (PGS). These include a commercial marine application of the MTEM (Multi-Transient ElectroMagnetic) method offshore Tunisia in 2008, successfully discovering hydrocarbons *before* drilling and the 2012 launch by PGS of a fully-towed commercially-viable marine MTEM system.

Significance and reach: Approximately 180 man-years of employment, with a value of more than $15M, have been provided in Edinburgh over the period January 2008 - December 2012.

Underpinned by: Research into electromagnetic survey methods, undertaken at the University of Edinburgh (1999 onwards), which led directly to the creation of MTEM Limited.

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.

Ziolkowski, Professor of Petroleum GeoScience (1992 onwards)
Wright, PhD Student (1999 - 2003) and Research Fellow (2010 onwards)
Hobbs, Senior Lecturer (1971 - 2007) and Honorary Professor (2007 onwards)

Research overview and context

Most oil and gas is produced from porous underground or sub-sea reservoirs discovered by seismic surveys. Seismic signals do not distinguish oil-saturated from water-saturated reservoirs, so exploration wells are drilled. Most (~75%) find no hydrocarbons and are “dry.” Since hydrocarbons are electrically resistive, whereas salt water is conductive, ElectroMagnetic (EM) methods have the potential to determine fluid content and thus reduce the number of dry wells. Research at the University of Edinburgh since 1999 has focussed on developing an EM approach that works: the Multi-Transient ElectroMagnetic 'MTEM' method. This is based on a major research-led innovation: separation of the complete scattered field impulse response from the total measured response by deconvolution - removing the effect of the measured source time function. This invention was first published as part of a patent application filed by the University of Edinburgh in 2001 and granted in the United States in 2005 **[1]**.

Key research findings that underpin the subsequent impact

During PhD work under the supervision of Ziolkowski and Hobbs, Wright worked on novel methods to process existing data from a European Commission-funded THERMIE project (1992 - 1998) that was led by Ziolkowski. The resultant analysis, published in 2002, showed a clear horizontal event, corresponding to resistive hydrocarbon gas in an underground gas storage reservoir 500 m beneath the survey line (Figure 16, **[2]**). A critical processing step was to use the impulsive air wave travelling at the speed of light to correct timing errors, of as much as 3 m, generated in the recording system **[2]**. The Edinburgh team realised immediately that such a method, described as MTEM, had the potential for detecting hydrocarbons from the surface before drilling. Following a successful Scottish Enterprise Proof of Concept project based on a gas storage reservoir in France (2003 - 2004), MTEM Limited was created in November 2004 and continued the French survey in collaboration with Total and the University of Edinburgh. Two key results from these initial surveys, described in a 2007 publication, were suppression of cultural noise – 50 Hz and its harmonics –

and inversion of the deconvolved data to identify the presence of known gas 500 m below the surface **[3]**. In 2007 - 2009, with £500k DTI funding, BP as collaborator and the University of Edinburgh as subcontractor, MTEM Limited developed time-lapse technology for monitoring production and identifying by-passed hydrocarbons. Two key results, described in a 2010 publication on the application of such methods to the North Sea Harding Field, were attenuation of magnetotelluric noise by up to 20 dB, and better repeatability than time–lapse seismic data **[4]**.

Petroleum Geo-Services (PGS) acquired MTEM Limited in 2007 and have since developed a fully-towed marine transient EM system for vastly improved data acquisition efficiency. A 2009 trial of this system compared square-wave and Pseudo-Random Binary Sequence (PRBS) source signatures. Ziolkowski and Wright (who returned to the University of Edinburgh in March 2010) analysed these data with J. Mattsson of PGS and showed in a 2011 publication that the PRBS signature was clearly superior both for resolution and for signal-to-noise ratio **[5]**. Recently published work has described a Bayesian approach to inverting MTEM data, using rock physics models, in order to compute background resistivity models from seismic and well-log data **[6]**.

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) and/or the 2012 Thomson Reuters Journal Impact Factor (JIF). The starred outputs best indicate this quality.

[1]* US patent for the MTEM method
Wright, D.A., A.M. Ziolkowski, and B.A. Hobbs (2005) 'Detection of Subsurface Resistivity Contrasts with Application to Location of Fluids', *United States Patent* Number 6,914,433.
The patent document is available at http://tinyurl.com/B7-10-S3-1B.

[2]* Peer-reviewed journal article describing the MTEM method, >30 citations
Wright, D., A. Ziolkowski, and B. Hobbs (2002) 'Hydrocarbon detection and monitoring with a multichannel transient electromagnetic (MTEM) survey, 2002', *The Leading Edge*, 21, 852-864, DOI: 10.1190/1.1508954

[3]* Peer-reviewed journal article demonstrating the MTEM method, >20 citations
Ziolkowski, A., B. Hobbs, and D. Wright (2007) 'Multi-transient electromagnetic demonstration survey in France', *Geophysics*, 72, no 4, F197-F209, DOI: 10.1190/1.2735802

[4] Peer-reviewed journal article, >10 citations
Ziolkowski, A., R. Parr, D. Wright, V. Nockles, C. Limond, E. Morris, and J. Linfoot (2010) 'Multi-transient electromagnetic repeatability experiment over the North Sea Harding Field', *Geophysical Prospecting*, 58, No. 6, 1159-1176, DOI: 10.1111/j.1365-2478.2010.00882.x

[5] Peer-reviewed journal article
Ziolkowski, A., D. Wright, and J. Mattsson (2011) 'Comparison of pseudo-random binary sequence and square-wave transient controlled-source electromagnetic data over the Peon gas discovery, Norway', *Geophysical Prospecting,* 59, 1114-1131, DOI: 10.1111/j.1365-2478.2011.01006.x

[6] Peer-reviewed journal article (Werthmüller is a PhD student at Edinburgh, 2010 onwards)
Werthmüller, D., A. Ziolkowski and D. Wright (2013), 'Background resistivity model from seismic velocities', *Geophysics*, 78, No.4, P E213-E223, DOI: 10.1190/geo2012-0445.1.

A further metric of research quality is given by several large grants that have contributed to the preceding outputs, which include:

- *Delineation and Monitoring of Oil Reservoirs using Seismic and Electromagnetic Methods* (1992 - 1998), sponsor: European Commission - THERMIE award, value: ECU1.3M + 1M French Francs from Elf Enterprise Caledonia Ltd., awarded to Ziolkowski with Deutsche Montan Technologie, U. of Cologne and Compagnie Générale de Géophysique.
- *Hydrocarbon Detection and Monitoring using an EM Method* (2003 - 2004), sponsor: Scottish Enterprise - Proof of Concept Project, value: £183k, awarded to Ziolkowski.

- *Monitoring production and identifying by-passed hydrocarbons using a multi-transient electromagnetic method* (2007 - 2009), sponsor: DTI Project H0531E, value: £1.2M, awarded to Ziolkowski and led through BP.
- *Strategic alliance to undertake research in geophysical data acquisition, processing and interpretation* (2010 - 2013), sponsor: PGS (large award reviewed at board level), value: £967k, awarded to Ziolkowski.

4. Details of the impact

Lettered references relate to corroboration sources in Section 5.

Economic benefits derived from the MTEM Limited spin-off company

Pathway: The successful creation of MTEM Limited in November 2004 **[A]** (funded by £7.4M from three equal investors: HitecVision, Energy Ventures, and Scottish Equity Partners) was a direct result of the initial research and subsequent Proof of Concept work by the Edinburgh research team. In 2007 PGS acquired MTEM Limited for $275M and in August 2012 the company became PGS EM Limited **[A]**. Evidence of the use, application and development by PGS of the MTEM approach, with extensive citation of the underlying research basis, can be found on the PGS website and in PGS technical documents **[B]**. Over the period January 2008 – July 2013, MTEM Limited / PGS EM Limited has provided three principal economic benefits:

- Provision of employment in the Edinburgh office.
- The undertaking of important commercial test studies of the MTEM method. An MTEM survey conducted in the Mediterranean Sea off the coast of Tunisia in 2008 on behalf of ENI (Italy) showed a resistive target that was drilled immediately, and confirmed the presence of hydrocarbons, as described in subsequent publicly available workshop proceedings **[C]**. Other offshore surveys over the period 2008 – June 2013 have shown that apparently promising reservoirs were not resistive and thus not worth drilling. Land surveys over the same period were undertaken in India and over the Athabasca tar sands in Canada, as stated by the President of PGS EM Limited **[B].** The marine MTEM system was also used in 2008 over a number of currently producing North Sea fields, including the Harding Field in the UK sector, then owned by BP and Maersk, a repeat of a survey performed in 2007 **[D]**.
- PGS has invested heavily in R+D related to MTEM technology since 2008, with particular emphasis on the development of a fully-towed system for marine applications. The 2012 PGS annual report indicates a total R+D spend across the whole company of $38.3M.

Significance and reach:

- Over the period January 2008 – December 2012 there were between 25 and 49 MTEM Limited employees in the Edinburgh office, which continues to undertake much of the R+D work. Over this period we estimate that approximately 180 man-years of employment have been undertaken in Edinburgh, with indicative staffing cost figures in excess of $15M, as evidenced in the published company accounts **[E]**. Furthermore, many former employees at Edinburgh have moved to jobs in PGS's offices in Oslo and Weybridge to work on the development, operation, and marketing of MTEM technology.
- The 2008 Tunisian application demonstrated the potential of the MTEM method to identify hydrocarbons before drilling. The results of this important commercial application were acknowledged by the oil company ENI (Italy) in 2010 workshop proceedings stating that: "*this represents a first important result that seems to confirm the value of MTEM methodology for relatively deep hydrocarbon exploration purposes"* **[B]**.
- The 2008 Harding study established that the MTEM method has the potential to monitor the production of hydrocarbons in a producing field, showing where hydrocarbons are being produced, and where by-passed hydrocarbons remain. This is very important for the production of remaining hydrocarbons in the North Sea, where about one third of the producible reserves remain in-place. The Harding test established the method potential with a key client (BP) and so is a key commercial milestone for PGS, now used as part of its marketing **[D]**. Research output [4], Section 3 was co-authored by a Geophysical Advisor at BP and all the claims in that paper were approved by BP before publication, including the

statement: "*The results indicate that the multi-transient electromagnetic method is suitable for exploration, appraisal, and monitoring hydrocarbon production"* **[F]**.

- In Oct 2012, PGS announced the successful validation of a fully towed streamer electromagnetic system **[G]**, which will considerably reduce acquisition costs for EM data.

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] Companies House record of MTEM Limited (since 2012, PGS EM Limited)

http://tinyurl.com/B7-10-S5-XA or http://tinyurl.com/B7-10-S5-A

Provides evidence of the existence of MTEM Limited (Registered number SC243297) and its renaming as PGS EM Limited in August 2012 (under the section entitled 'PreviousNames').

[B] PGS publications describing the application and development of the MTEM approach

I) Press Release: "Launch of the North Sea MTEM Campaign" (April 2008)
http://tinyurl.com/B7-10-S5-XB1 or http://tinyurl.com/B7-10-S5-B1

II) Exploration Technology (PGS Newsletter) article on "Laws of Attraction, The use of electromagnetics in exploration is revolutionising the way operators view their reservoirs" (August 2008) http://tinyurl.com/B7-10-S5-XB2 or http://tinyurl.com/B7-10-S5-B2

Collectively provide evidence of the distinctive use of MTEM science by PGS since 2008, including applications in identification of hydrocarbons prior to drilling and the success of onshore MTEM surveys in Canada and India (quote from the President of PGS EM Limited on Page 6 of II).

[C] Presentation at the EGM 2010 International Workshop (Capri, Italy, April 2010)

Multi Transient Electromagnetic method in shallow water: a case history in the Mediterranean Sea, D'Arienzo, D., Dell'Aversana, P., Cantarella, G., and Visentin, C.
http://tinyurl.com/B7-10-S5-XC or http://tinyurl.com/B7-10-S5-C

Provides evidence of the successful application by ENI (the authors are all employed by ENI) of an MTEM survey (citing underpinning research output [2], Section 3) in the Mediterranean Sea in 2008, including its *'value for relatively deep hydrocarbon exploration purposes'* (Page 4).

[D] PGS Tech-Link magazine article (August 2009)

A Multi-Transient EM Repeatability Experiment Over The North Sea Harding Field (TECH LINK, Vol.9, No. 8, Aug 2009) http://tinyurl.com/B7-10-S5-XD2 or http://tinyurl.com/B7-10-S5-D2

Provides evidence of the Harding Field application of the MTEM method in a producing field (Pages 1 and 6) and of PGS using this case study in marketing, illustrating its importance as a business milestone. Underpinning research outputs [1,2,4], Section 3 are directly cited on Page 6.

[E] Directors' report and financial statements from MTEM Limited for the years 2009 and 2010 and PGS EM Limited for the year 2011, obtained from Companies House

Documents may be obtained directly from Companies House or are available upon request. These provide evidence of the staff numbers and costs cited, based on summation of years 2008 and 2009 in the report dated 31 December 2009 (page 17) and years 2010 and 2011 in their respective years (Page 16 and Page 15 respectively). Staff numbers and costs for 2012 are known to be similar to those for 2011 and are included in the quoted figures on that basis. Note that the 2011 accounts are filed under PGS EM Limited, although the change of name occurred in August 2012.

[F] Geophysical Advisor, BP

Can provide corroboration of the successful nature of the Harding Field application of the MTEM method and that the quoted statement from the published paper was approved by BP.

[G] PGS press release (October 2012) on the launch of a fully-towed EM streamer system

http://tinyurl.com/B7-10-S5-XG or http://tinyurl.com/B7-10-S5-G

Provides evidence of PGS's continuing investment and success in developing new EM technologies, including the long-standing business development goal of a towed streamer, and of the role played in this by the acquisition of MTEM Ltd. Web-pages linked from this one provide sample survey results.