Institution: University of Southampton

Unit of Assessment: 07 Earth Systems and Environmental Sciences

Title of case study: 07-11 Hydrocarbon exploration using marine electromagnetic techniques

1. Summary of the impact

Resistivity anomalies resulting from hydrocarbon reservoirs can be located and measured using controlled source electromagnetic (CSEM) techniques. The University of Southampton played a pivotal role in the first full-scale marine CSEM survey over a hydrocarbon target in late 2000. This survey and subsequent work spawned one of the greatest technological advances in the field of oil exploration since the development of 3D seismic techniques. By the end of 2012 over 650 commercial CSEM surveys had been completed worldwide, with annual survey revenues in excess of US$200 million. The University continues to develop impact through consultancy and industry-funded research projects.

2. Underpinning research

Controlled source electromagnetic (CSEM) techniques represent arguably the most significant technological advance in the field of oil exploration since the introduction of 3D seismic surveying. University of Southampton (UoS) staff have played a pivotal role in devising, refining and applying these revolutionary methods.

Electromagnetic surveying can determine directly whether a potential hydrocarbon reservoir identified in seismic data has high or low electrical resistivity. This is important, as the resistivity of sedimentary rocks whose pore spaces are saturated with saline, aqueous fluids is low – just a few times that of seawater – whereas the resistivity of those whose pore spaces are predominantly filled with oil or natural gas is much higher.

Southampton academics have led the world in CSEM for more than a decade **[3.1-3.6]**. Their contributions have included the development of survey geometries that provide a diagnostic indicator of hydrocarbons' presence; a deep-towed transmitter strong enough to overcome the signal attenuation caused by seawater; and receivers of unprecedented sensitivity.

The first full-scale demonstration of this technology took place in late 2000. Professor Martin Sinha (Professor of Earth Sciences, 2000-2013) was the scientific lead of a project conducted with Norwegian oil and gas company Statoil and Scripps Institution of Oceanography. Southampton provided the bulk of the equipment and crucial elements of the survey design for the study, that was carried out on the RRS *Charles Darwin*, offshore from Angola **[3.2-3.4]**.

Other Southampton personnel included Dr Lucy MacGregor (NERC Research Fellow, 2000-2002; co-founder of OHM, 2002) and Jenny Rust (Instrumentation Engineer, 2000-2002; co-founder of OHM, 2002). Southampton worked with Scripps to process, analyse, model and interpret the data, and with Statoil and other partners, including ExxonMobil, to verify the method. It became clear this was a surveying technique to complement the existing seismic approach. The subsequent rush to commercialisation resulted in two spinout companies: Southampton's Offshore Hydrocarbon Mapping (OHM) and Statoil's EMGS, both founded in 2002.

UoS transferred the relevant technology, data analysis techniques and software tools to OHM, and Southampton and OHM began working in tandem. The company was floated on the London Stock Exchange's Alternative Investment Market in 2004, when it was valued at £49.3 million. From 2002 to 2006 Southampton and OHM defined, sought patent protection for, and defended intellectual property generated by the research – a process that included licensing and transferring patents to OHM.

Building on its earlier research, between 2003 and 2007 Southampton optimised the quantitative analysis of co-located seismic and electromagnetic geophysical datasets. This was achieved by developing effective medium models that enabled the enhanced investigation of data relating to

sub-surface reservoirs. Sinha, Michelle Ellis (PhD student 2003-2008, post-doctoral researcher UoS 2008-2009, NERC-NOC 2009-2010, then scientist and product manager OHM/Rock Solid Images 2010-present), Professor Tim Minshull (Professor of Geophysics) and Dr Angus Best (Research Geophysicist, NERC-NOC) were involved in this work.

From 2007 to 2009 Sinha, MacGregor and Ellis developed higher-resolution CSEM technologies through the HyPoMap (hydrocarbon pocket mapping) project **[3.6]**. This work aimed to prolong the productive life of mature and declining oil provinces, as well augmenting oil and gas recovery from them. Ongoing research, led by Sinha, MacGregor and Best, has been focused on acquiring and upscaling data from reservoir rocks with a view to validating models of joint seismic-electrical properties.

3. References to the research (the best 3 illustrating quality of work are starred)

***[3.1]** MacGregor, L., Sinha, M. C. and Constable, S. (2001) Electrical resistivity structure of the Valu Fa Ridge, Lau Basin, from marine controlled-source electromagnetic sounding. Geophysical Journal International,146, (1), 217-236. (doi:10.1046/j.1365-246X.2001.00440.x).

***[3.2]** Ellingsrud, S, Eidesmo, T, Johansen, S, Sinha, MC, MacGregor, LM, and Constable, S (2002): Remote Sensing of Hydrocarbon Layers by Sea-Bed Logging (SBL): Results from a Cruise Offshore Angola, *The Leading Edge*, 21, 972-982

***[3.3]** Eidesmo, T, Ellingsrud, S, MacGregor, LM, Constable, S, Sinha, MC, Johansen, S, Kong, FN, and Westerdahl, H (2002): Sea-Bed Logging (SBL), a New Method for Remote and Direct Identification of Hydrocarbon-Filled Layers in Deepwater Areas, *First Break*, 20, 144-152

[3.4] Sinha, MC (2012): Survey Design and Acquisition Parameters for Marine CSEM Prospecting: Key Principles and Considerations, in *Electromagnetics for Oil Exploration*, Strack, KM, and Thomsen, L (eds), Society of Exploration Geophysicists (accepted)

[3.5] Ellis, Michelle H., Sinha, Martin C., Minshull, Tim A., Sothcott, Jeremy and Best, Angus I. (2010) An anisotropic model for the electrical resistivity of two-phase geologic materials. Geophysics, 75, (6), E161-E170. (doi:10.1190/1.3483875).

[3.6] Ellis, Michelle H., Sinha, Martin C., and Parr, Ronnie (2010) Role of fine-scale layering and grain alignment in the electrical anisotropy of marine sediments. First Break, 28, (9), 49-57.

Research Funding: Major contracts prior to formation of spin-out companies:

1. Statoil research contract 4500203815, Seabed Logging Offshore Survey, Seafloor Electromagnetic Sounding Block 17, offshore Angola, to University of Southampton (2000) – £608,220
2. ExxonMobil research contract B463353. Surveys in West Africa – RRS Charles Darwin cruise CD137 to University of Southampton (2001). – Funding £248,538.
3. ExxonMobil research contract B853313. DASI Surveys – RRS Charles Darwin to University of Southampton (2001) – Funding £1,190,042
4. ExxonMobil research contract B99V14, DY257. Trials cruise offshore Ireland – RRS Discovery cruise 275 to University of Southampton (2001). – Funding £308,165

Major Research contracts after formation of spin-out companies:

1. TSB/NERC contract. DT/E005616/1 HyPoMAP Reservoir characterisation by integrated seismic and electromagnetic remote sensing. (2006-2009). Funding via NERC £350,448
2. Rock Solid Images Plc. 2008-2013. Contract: 506827101. Upscaling of elastic wave and electrical properties of reservoir rocks. £253,000

4. Details of the impact

The need for greater ingenuity in locating and extracting fossil fuels has long been recognised in the face of the increasingly widespread exploitation of the most obvious and easily accessible reserves. The development of CSEM techniques at the University of Southampton has not only made one of the most significant contributions ever to satisfying this need: it has also given birth to an entirely new and commercially viable industry. As noted by Chief Research Geoscientist at ExxonMobil upstream research **[5.1]** "*The University of Southampton group led by Martin Sinha and Lucy McGregor had a key role in the design and successful completion of the first electromagnetic survey over a hydrocarbon target in 2000. Subsequently this group have significantly contributed to the development of the new CSEM industry*".

That industry continues to flourish today. This is illustrated by the enduring success of the two spinout companies formed in the wake of the first large-scale demonstration of CSEM and by the ever-growing evidence of the technology's sustained value in the field of exploration.

Southampton's spinout firm, OHM, acquired Rock Solid Images, a company specialising in rock physics and quantitative seismic interpretation, in 2007. Following divestment of the CSEM acquisition division of the company (along with the OHM brand and name) the company was re-named Rock Solid Images in 2010. It currently employs 45 staff **[5.2]**; Sinha stepped down from the board in 2006. As an industry leader in the integration of CSEM, seismic and well log data, RSI has provided services to clients including international oil companies, small independents and national oil companies.

The second company, EMGS, was formed in 2002 as a spinout from Statoil. In 2011 EMGS acquired the former OHM acquisition division from its new owners for over US$19 million. EMGS annual reports show that between 2008 and 2012 annual revenue has increased by over 70% from US$116 million to greater than US$200 million, with a particularly large increase of 129% between 2010 and 2011 **[5.3].** In its 2012 annual report EMGS, which currently employs more than 270 people states that more than 650 CSEM surveys have been completed and observes: "*In recent years the company's customers and large oil-consuming and gas-consuming nations have perceived a growing and potentially lasting imbalance between the supply of and demand for hydrocarbons. The demand for EM services increased in 2011 and 2012*."

This assertion is clearly supported by continued investment in survey acquisition and analysis by a variety of oil majors (such as Statoil, Shell, ExxonMobil and Chevron) and national oil companies (such as PEMEX, Petrobras and Petronas). Since 2010 it has also been supplemented by a number of studies that have highlighted CSEM's impact on exploration in terms of substantially reducing risk and boosting success rates for drilling – a particularly important benefit when companies cannot legally book a surveyed site as an asset (for instance, for the purpose of informing shareholders) until drilling has taken place.

For example, according to research published in *The Leading Edge* **[5.4]** the monthly magazine of the Society of Exploration Geophysicists, prospects that show a significant resistive anomaly are approximately twice as likely to contain hydrocarbons than those that do not. The study, the most extensive of its kind to date, said: "*It seems a fair conclusion that the incorporation of CSEM data into [an] oil company's work flow can significantly help de-risk prospects*."

Research that appeared in May 2010 **[5.5]** in *First Break*, a leading publication serving the geoscience and engineering community, revealed that, conditional on non-commercial discoveries being counted as dry wells, the drilling success rate is 50 per cent to 70 per cent for wells drilled on prospects exhibiting a significant resistive anomaly – compared with just five per cent to 14 per cent for wells drilled on prospects without such an anomaly. The study concludes: "*The dollar value of CSEM will show itself through a correct and repeated application in a portfolio setting… The current empirical results suggest a very significant value [for CSEM] in exploration settings*."

ExxonMobil were one of the pioneers of CSEM (which they call R3M) in the hydrocarbon industry. They apply the technology to improve success rates of offshore exploration activities in deepwater, where a single wildcat well can cost more than US$100 million. In the past 10 years, ExxonMobil has acquired more than 70 marine surveys using CSEM technology, which has accurately confirmed the predicted geological setting more than 70 % of the time **[5.6]**.

Shell use CSEM in favourable environments, including Tertiary plays. Karman et al. (2011) report that they have drilled 27 wells on a selection of 100 prospects mapped with CSEM since 2002. Of those 27, 22 were discoveries (81% success rate, with an average pre-CSEM success rate for these prospects of 47%), 17 had conclusive CSEM interpretations (defined as those where a positive prediction was made). 15 of those that were predicted to be discoveries were. The remaining two were predicted to be dry and this was confirmed by drilling **[5.7]**.

Southampton's work – which is currently continuing in collaboration with Rock Solid Images and partners including oil major BP – has been recognised with several awards and honours. In 2008 the Geological Society of London presented Sinha with the William Smith Medal **[5.8]**, which is awarded annually for outstanding research in applied or economic geology. In 2011 MacGregor was appointed the Society of Exploration Geophysicists' Honorary Lecturer for Europe in acknowledgment of not only her own contributions to the field of CSEM analysis and data integration but also of CSEM's general impact and growing importance in reservoir exploration and appraisal **[5.9]**. Recent research has been endorsed by industry: *"BP found the HyPoMap (Hydrocarbon pocket mapping) project to be particularly useful in developing CSEM technologies."* **[5.10]**.

5. Sources to corroborate the impact

[5.1] Chief Research Geoscientist at Exxonmobil upstream research co. Current President of European Association of Geoscientists and Engineers.

[5.2] Chief Technology Officer, Rock Solid Images plc,

[5.3] EMGS Annual Reports http://www.emgs.com/annual_reports/

[5.4] Hesthammer, J, et al (2010): CSEM Performance in Light of Well Results, *The Leading Edge*, January 2010, 35-41 www.emgs.com/content.ap?contentId=456

[5.5] Fanavoll, S, et al (2010): Controlled Source Electromagnetic Technology and Hydrocarbon Exploration Efficiency, *First Break*, May 2010, 61-69 www.emgs.com/content.ap?contentId=506

[5.6] http://news.exxonmobil.com/press-release/exxonmobil-receives-excellence-awards-technical-and-social-development-world-petroleum

[5.7] Karman, G., Ramirez, D., Voon, J. and Rosenquist, M. [2011] 'A decade of controlled-source electromagnetic, CSEM, in Shell: lessons from a global look back study', presented at the 4th NPF Biennial Petroleum Geology Conference, Bergen.
http://old.npf.no/course.php?page_c=6&id=694&time=373&w_lang=en&c=0&a=program

[5.8] Sinha awarded Geological Society of London's William Smith Medal, 2008
http://www.southampton.ac.uk/mediacentre/news/2008/jul/08_143.shtml

[5.9] MacGregor appointed Society of Exploration Geophysicists' Honorary Lecturer for Europe, 2011 http://www.seg.org/education/lectures-courses/honorary-lecturers/europe/macgregor/abstract

MacGregor, LM (2012): Integrating Seismic, CSEM and Well Log Data for Reservoir Characterisation, *The Leading Edge*, March 2012, 268-277
http://www.seg.org/resources/publications/tle/non-technical/-/tlent/31/03/0268

[5.10] Geophysical Advisor at BP. Specialist in non-seismic geophysics. Industrial liaison on HyPoMap (Hydrocarbon pocket mapping) project.