Institution:

University of Leeds

Unit of Assessment:

7, Earth Systems and Environment Sciences

Title of case study:

Case study 7: Sedimentology research steers high-value decisions in the hydrocarbon industry

1. Summary of the impact (indicative maximum 100 words)

University of Leeds Research has been used by its specialist Turbidites Research Group (TRG) to underpin consultancy work for oil companies that has, in turn, steered them to make high-value decisions. Examples include an oil well placement, the development of an oil field, and a decision to only partially develop another. The TRG has been funded by 14 oil companies since 1992, and its annual income has risen from £125k/yr prior to 2008 to £380k/yr during the REF period. It is estimated that the cumulative value of oil company decisions based on TRG research exceeds several hundred million dollars. Following the impact, Leeds have replicated the TRG business model to form new specialist industrial research groups that have each generated further impact.

2. Underpinning research (indicative maximum 500 words)

The aim of the TRG, led by **Bill McCaffrey**, is to study deep marine clastic sedimentary systems, which involves research into flow dynamics and deposits of turbidity currents and related flow types via outcrop studies, flume experiments, seismic studies and theoretical approaches. Gas and oil can be found in such marine sedimentary systems, and improved understanding of the processes involved in deposition leads to a better capacity to characterise and predict the properties of gas and oil reservoirs, which is of critical economic benefit to the oil industry.

The presence of channels in sedimentary systems has an important bearing on the architecture of the system and on reservoir characteristics. To obtain insights into the formation of these submarine channels and to be able to predict the patterns of sediment deposition within and around them, **McCaffrey** led field research into sedimentary rock channel formations in the French Alps as an analogous system **[1, 2]**. The research has resulted in improved understanding of processes such as channel incision, infill dynamics and other characteristics that can be applied to deep marine environments, and led British Gas (BG) to part-fund the work of Rufus Brunt (PhD student, University of Leeds 2000–2003)

In 2003, **McCaffrey** and collaborators from University College Dublin were the first to recognise a previously unknown type of deposit, the hybrid event bed phenomenon **[3]**. This type of sediment deposition gives rise to a range of sandstone architectures, which in turn affect the potential oil- or gas-bearing properties of the rock. This model of hybrid sediment flow was subsequently integrated with other models and refined by **McCaffrey** and co-workers in 2009 **[4]** to create a generic model of hybrid sediment gravity flow deposits that can be used to predict sediment architectures – and hence reservoir characteristics – in a wide range of settings.

In 2008, the TRG developed new models to account for patterns of deposition in sedimentary systems, providing key insights into the observed sandstone architectures and their spatial distribution **[5]**. In this work, co-authored by **McCaffrey** with collaborators from University College Dublin and industry, sedimentological analysis of Britannia core showed that spatial variability in the depositing particulate gravity currents produced corresponding spatial variability in the deposited reservoir sandstones in a way that was predictable and which could be exploited.

Between 2006 and 2009, new research led by **McCaffrey** has led to the finding that large scale slope failure could leave behind a newly defined “evacuated” bathymetric morphotype **[6]**. This bathymetry can be shown to control the location and orientation of the elongated sandstones comprising the middle part of the Britannia reservoir. The study also introduced the concept of the scale of observation required to substantiate sediment architecture models reliably.

Key researcher:

Bill McCaffrey, Research Fellow, Senior Research Fellow, and Principal Research Fellow (1993-2007) and Professor of Clastic Sedimentology (2008-present) in the School of Earth and Environment, University of Leeds; NERC Knowledge Exchange Fellow (2011-present).

3. References to the research (indicative maximum of six references)

1. **McCaffrey, W.D.**, Gupta, S. and Brunt, R. (2002). Repeated cycles of submarine channel incision, infill and transition to sheet sandstone development in the Alpine Foreland Basin, SE France, *Sedimentology*, **49**, 623-635 DOI 10.1046/j.1365-3091.2002.00477.x
2. Brunt, R.L. and **McCaffrey, W.D.** (2007). Heterogeneity of fill within an incised channel: the Oligocene Grès du Champsaur, SE France, *Marine and Petroleum Geology*, **24**, 529–539. DOI 10.1016/j.marpetgeo.2007.02.002
3. Haughton, P.D.W., Barker, S. and **McCaffrey, W.D**. (2003). 'Linked' debrites in sand-rich turbidite systems - origin and significance. *Sedimentology*, **50**, 459-482. DOI 10.1046/j.1365-3091.2003.00560.x
4. Haughton, P.D.W., Davies, C., **McCaffrey, W.D.** and Barker, S.D. (2009). Hybrid sediment gravity flow deposits – Classification, origin and significance. *Marine and Petroleum Geology*, **26**, 1900-1918. DOI 10.1016/j.marpetgeo.2009.02.012
5. Barker, S.P., Haughton, P.D.W., **McCaffrey, W.D.**, Archer, S.G. and Hakes, B. (2008). Development of rheological heterogeneity in clay-rich high-density turbidity currents: Aptian Britannia Sandstone Member, U.K. Continental Shelf, *Journal of Sedimentary Research*, **78**, 45-68. DOI 10.2110/jsr.2008.014.
6. Eggenhuisen, J.T., **McCaffrey, W.D.** Haughton, P.D.W., Butler, R.W.H., Moore, I., Jarvie, A. and Hakes, W.G. (2010). Reconstructing large-scale remobilisation of deep-water deposits and its impact on sand-body architecture from cored wells: The Lower Cretaceous Britannia Sandstone Formation, UK North Sea, *Marine and Petroleum Geology*, **27**, 1595-1615. DOI 10.1016/j.marpetgeo.2010.04.005.

4. Details of the impact (indicative maximum 750 words)

The TRG has been active since 1992. Total income to date is £3.9M (£185k/yr), with up to 14 companies supporting each of two three-year phase; income during the REF period (2008-2013) has grown to £1.9 million (£380 k/yr). Some (BP, BG, Concoco/ConocoPhillips) have been members through each phase. The impacts detailed below focus on examples of direct consultancy applying TRG research results, as these are most easily quantifiable.

i. TRG research outputs were incorporated into workflows for appraisal and development of the Britannia Field by Britannia Operator Ltd (BOL: jointly owned by ConocoPhillips and Chevron). Reservoir complexity and potential reservoir variability away from well control have been key issues on Britannia, accounting for significant volumetric uncertainty and representing the primary risk for new drilling opportunities. TRG research **[5]** led to a new model for the spatial variation of rheology within the particulate sediment gravity flows responsible for depositing the main reservoir interval, which directly impacted predictions of spatial variation in primary rock quality. These anticipated variations were explicitly incorporated into the reservoir model rebuild, providing a more robust depositional framework upon which to base new well prognoses. New well locations have been planned under the guidance of this improved depositional framework. Because infill wells cost upwards of $20M each, the decision to sanction each new one is significant. Significant new reserves were booked as a result of this programme. To date, subsequent drilling has corroborated the revised depositional framework in the upper reservoir intervals. TRG research also **[6]** led to a reassessment of the significance of debris flow deposits interleaved with sand beds in the lower Britannia reservoir intervals and a greater appreciation of the potential role of large-scale remobilisation processes. To this end, revisions to the existing correlation scheme were made and incorporated into the subsequent reservoir model updates for the Britannia field. These changes represent a significantly improved representation of the field's depositional architecture, and have

aided its profitability **[A]**.

ii. Research results from the TRG field programme **[1,2]** played a key role in the sanction decision and modelling of the BG-operated Blake Field. TRG provided a field workshop for the asset team, and company geologists used TRG field data to gain management support for the geological model and sanction development. Sanction involves the decision to go forward and develop a discovery for production – an investment of hundreds of millions of dollars. The Blake Field has subsequently been a production success **[B]**. Additional consultancy work was focused on building a model to justify extension drilling in the field "Blake Flank" (2005-present). The key insights were based upon the constraint of excisional channel geometries, the anisotropy of the depositional elements comprising the channel fill and the nature of the contacts between the channel fill and substrate sheet-form sandstones into which the channel incised.

iii. The TRG was commissioned to review two cores taken from an oil field off Australia and investigate the impacts of any revision in interpretation upon the inherited model (deposition in a relatively small sandy turbidite fan). The TRG core review, drawing upon underpinning research **[4, 6]** resulted in two new insights into the sedimentology of the field, which contributed to a re-interpretation of the depositional model in terms of a hybrid-event-prone fan. The revised depositional model raised concerns regarding the abundance and continuity of net pay within the reservoir. TRG insights contributed to the operator's internal assessment, which culminated in the proposal of a single well development plan focusing only on the gas contained in the field. Given the improved geological understanding of the field, appraisal was not seen as a viable economic option and development was only considered feasible in the context of the operator's other close-by assets and infrastructure. The TRG's work thereby contributed to making multi-million dollar decisions such as avoiding the costs of drilling an additional appraisal well and, potentially, of committing to an uneconomic oil development **[C]**.

Approach to following through on impact:

The TRG business model entails the development of research and consultancy, and the provision of bespoke databases that allow structured access to the literature and to metadata on sedimentary architecture. Sponsors have joined and re-joined the TRG because of their perceived benefits in each of these categories. TRG outputs are delivered via a KE-oriented website, described by sponsors as industry-leading through its impact on key workers. This model has been cloned to develop three new industry-facing research groups at the University of Leeds; the Fluvial Research Group (FRG), the Shallow Marine Research Group (SMRG), and the Basin Structure Group (BSG). The effectiveness of this cloning in widening research impact is illustrated by the level of company support for these new ventures; the FRG is now in its second three-year phase, currently with seven sponsor companies, and the SMRG and the BSG have just launched, with one and four sponsor companies, respectively.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Letters of corroboration are available upon request

A. Letter of corroboration from Subsurface and Drilling Manager, Britannia Operator Limited.

B. Letter from Head of Geology, BG Group.

C. Corroboration from Development Geology Adviser. The company has asked that it and the field remain confidential; contact details can be provided to the panel in confidence.