Institution: Royal Holloway, University of London

Unit of Assessment: Earth Systems and Environmental Sciences

Title of case study: Numerical Modelling of Turbidity Currents

1. Summary of the impact

Waltham's software, developed at Royal Holloway, is impacting on the oil and gas industry. For Statoil, one of the beneficiaries, it *"influenced multi-million pound decisions"* (*Doré, Statoil Chief Geologist 2012*) in their exploitation of the Gudrun oilfield, which required a £5 billion exploration investment. The software predicts the location of oil and gas reservoirs by simulating their formation by turbidity currents. The Royal Holloway software was commercialized by Midland Valley Exploration Ltd (*MVE*), used in consultancy work and sold to major oil-companies. Sales have generated £120k (*Q3-2008 to Q2-2011*) and created high-quality employment for three staff members at MVE.

2. Underpinning research

The research was led throughout by Dr. Waltham (Royal Holloway academic *employee since 1986*) and two post-doctoral research assistants (*Dr. Weiguo Sheng, 2010 and Dr. Peter Rowley, 2011-2012*).

- The underpinning research at Earth Sciences Royal Holloway developed a mathematical model that allows rapid and accurate numerical modelling of turbidity currents and their deposits using the minimum number of unknown parameters. The original mathematical model (*Waltham & Davison 2001*) was similar to the published depth-averaged models used by other groups and ultimately the approximations used meant that the model had limitations. Royal Holloway scientists then developed and introduced new methods of quantifying basal friction (*Waltham 2004 & 2008, Waltham et al 2008*) that allowed friction-factors and particle suspension to be related to other quantities such as flow thickness and seafloor roughness. As a result, the list of unknown factors controlling any given flow was substantially reduced in this methodology. Furthermore, Royal Holloway scientists demonstrated that a simple genetic-searching algorithm can be used to efficiently find the remaining model parameters (e.g. flow thickness, flow density etc) (*Waltham et al 2008*). These parameters are required to produce a turbidity current whose deposits can match those seen in the available wells for the particular region or field under consideration. This approach proved to be particularly useful for excluding unlikely scenarios, e.g. flows entering a modelled region from all but a narrow range of directions (*Waltham et al 2007*). Hence, ancient flows can be reconstructed using limited data concerning the deposit properties (*e.g. sand and mud thicknesses in a few well locations*). Such a model "inversion" approach allows deposit thickness and porosity to be predicted in areas devoid of data (*i.e. between the wells*) thus allowing the overall sand-distribution to be evaluated. The sand-distribution is a key piece of information for oil-exploration in turbidite sands.

- The initial research was carried out as part of a research project funded by the British Gas Group and Badley-Ashton Ltd in 1999-2002 (*£31k*). The work was continued in a research project funded by Midland Valley Exploration Ltd (MVE) in 2006-2007 (*£46k*) and is now ongoing and funded jointly by MVE and the Technology Strategy Board (*2009-2013, £465k*).

3. References to the research

Research quality

Waltham, D, 2004. Flow Transformations in particulate gravity currents. *J. Sedimentary Research* **74**, 129-134.

Waltham, D, Jaffey, N, MacLean, S & Zampetti,V, 2008. Combined Structural Reconstruction and Stratigraphic Modelling of Turbidite Prospects using 3D Seismic Data. *Petroleum Geoscience*, **14**, 1-9.

Waltham, D, 2008. Slope Control on Submarine Channel widths. *J. Sed. Res.,* **78**, 317-322.

Applications

Waltham, D, Pickering, K, & Bray, V, 2007. Particulate Gravity Currents on Venus. *J. Geophys. Res.* (Planets), **113**, E02012, doi:10.1029/2007JE002913.

Waltham, D & Davison, I, 2001. Obstacles and Sinks: Effects on turbidite flow on deepwater continental margins. In: *GCSSEPM 21st Annual Research Conference*, 511-522.

Research Grants (total £543k)

a) 3D Stratigraphic Simulation: Towards a Practical E&P tool. Funded by BG Group and Badley Ashton Ltd. PI; D Waltham. 1999-2002, £31k.
b) Commercialization of turbidite deposit modelling software. Midland Valley Exploration. PI; D Waltham. 2006-2007, £46k.
c) Turbidite Forward Modelling for Improved Reservoir Models. Joint with Midland Valley Exploration Ltd. Technology Strategy Board. PIs; D Waltham (Royal Holloway) and C Dunlop (Midland Valley Exploration Ltd). 2009-2012, £465k.

4. Details of the impact

The research resulted in a stable, fast and accurate algorithm for forward and inverse modelling of turbidity currents and their deposits. The model incorporates novel aspects of particulate gravity-current physics, such as friction factors and suspension criteria based upon fluid-mechanics principles, rather than empirical relationships. As a result, thousands of simulations can be run overnight on simple desk-top PCs thus bringing sensitivity analyses and “mathematical inversion” of turbidity current models to the desktop-computers of geologists at the forefront of exploration in oil-companies. In summary, these developments resulted in the development of highly efficient software that allows users to rapidly understand and characterize turbidite deposits.

The practical use for this software is to find a simulation that accurately reproduces ancient sand deposits observed in wells. The model then predicts the sand distribution over the entire modelled area, thus identifying promising locations for future drilling. The areal distribution and thickness of the modelled sand bodies also allows for prediction of the reservoir volume that is an important factor in deciding the financial risk of further exploration. Finally, the sand distribution can be fed into industry-standard fluid-flow models that predict the ease with which hydrocarbons (*oil & gas*) can be extracted from the sand. This allows for the assessment of recoverable (*as opposed to in-place*) reserves that constrains the exploitation strategy (*e.g. placement of water-injection wells*).

The Royal Holloway program was commercialized by Midland Valley Exploration Ltd. during 2008. MVE's contribution was to build a user-friendly interface and, most importantly, to integrate the modelling with their own world-leading structural-reconstruction software. Structural reconstruction allows ancient seafloor bathymetry to be estimated from 3D seismic data and this bathymetry is a key input to the turbidity current modelling. The combination of structural reconstruction and forward/inverse modelling of turbidity currents is unique with no one else yet providing this capability in either industry or academia.

Since its release, the software has been sold to nine commercial clients including major oil-companies and smaller consultancy companies. In addition the software has been purchased by ten universities. Also, MVE have used the software on three consultancy projects. The names of the specific companies involved and the financial details are commercially sensitive. However, Royal Holloway received a 30% royalty on all sales and consultancy indicating that MVE were paid £120k between Q3-2008 and Q2-2011. As a result of Royal Holloway involvement in marketing and support, we know that Shell, Nexen, Noble Energy, RepSol and StatOil are some of the companies who have evaluated the software. Income from sales together with Government-funds for supporting further development have allowed MVE to employ three top-level people in their UK office to market and develop this product.

In 2009 StatOil used the results of turbidite modelling during reassessment of the Gudrun field in the Norwegian North Sea. Gudrun was discovered in 1974 but was not exploited at that time because of the technical difficulties of extracting oil from this geologically complex field. However, the technical capability now exists to exploit such resources and so its modern commercial potential was reassessed during 2009. This included an evaluation of reservoir size, location, compartmentalization and quality, in order to develop the most cost-effective drilling strategy. Results from Royal Holloway software modelling contributed to this study. In particular the software was used to evaluate the impact of compartmentalization of sand-bodies resulting from contemporary folding and faulting and to evaluate uncertainty in sand-body location related to the unknown entry points of the turbidity currents. As a result of the reassessment, a plan of development and operation (PDO) was submitted to the Norwegian government and accepted in 2010. Engineering work began in late 2010 and the field will come on-line in 2014. Gudrun is currently believed to hold oil and gas reserves worth $13billion. To exploit this field $3.5 billion is being invested by Statoil during the period 2010-14. Exploitation of the Gudrun field will help to secure energy supplies in western Europe at a time when many oil-rich regions of the world are becoming increasingly volatile and unreliable.

5. Sources to corroborate the impact

1. Midland Valley Exploration Ltd are able to confirm that the modelling algorithm is RHUL IPR (MVE have supplied the interfaced and, most vitally, a link to their own structural restoration software which makes this a powerful package). They can also confirm the software sales, the number of educational establishments using free copies and the income from associated consultancy projects:
   http://www.mve.com/software/sediment-modelling Click "features tab".

2. Royal Holloway's R&E Department are able to confirm royalty payments.

3. The project manager and managing director of MVE can be contacted to corroborate the Royal Holloway contribution to the project and to corroborate industry use of the

software.

4. The Vice-President for Global Exploration, Statoil will confirm that the software was used in the North Sea project discussed in the statement. They will also confirm that the software played a significant role in focussing their interpretation on the issue of “sand-body compartmentalization” and that they subsequently invested extremely large sums in field development.