Institution: University College London (UCL)

Unit of Assessment: 7 – Earth Systems and Environmental Sciences

Title of case study: Improved geological models aiding hydrocarbon reservoir development

1. Summary of the impact

UCL's Deep-Water Research Group (DWRG) creates knowledge transfer between research and the hydrocarbon industry. Oil companies use the DWRG's research results to generate improved in-house computer-generated hydrocarbon reservoir models, allowing them to manage, develop and value their reservoirs better. The same companies also use the research to run training courses for employees, including reservoir engineers and managers, leading to improved understanding and more informed decision-making about the management of hydrocarbon reservoirs. Improved management and development of reservoirs ultimately leads to oil companies being able to extract a greater amount of oil.

2. Underpinning research

The Ainsa sedimentary basin in the Spanish Pyrenees contains cumulatively around 4 kilometres of exhumed conglomerates, sandstones and shales that accumulated in a deep-marine seaway in the order of ~500 metres water depth over 10 million years in the Middle Eocene time period (~50-40 Ma). The basin formed part of a connected seaway along the length of what are now the foothills of the Pyrenean mountain belt. It was around 150 kilometres in length and was connected to a palaeo Bay of Biscay. The clastic sediments that accumulated in the Ainsa basin (and the time-equivalent and connected Jaca and Pamplona deep-marine basins to the east) formed submarine fans and associated deposits that were supplied mainly from rivers and deltas of the rising Pyrenean orogen to the north and east. These sediments provide arguably the most complete and linked ancient sedimentary system anywhere in Europe, and indeed globally. As such, these sediments are of considerable interest to the hydrocarbon industry as analogue models for many sites of hydrocarbon exploration and production worldwide, and for training technical staff (geologists, geophysicists, palaeontologists, reservoir engineers).

UCL's DWRG, based in the Department of Earth Sciences and led by Kevin Pickering (Professor 1993-present), managed an integrated outcrop-subsurface study of the deep-marine sandy submarine-fan deposits in the Ainsa basin (Ainsa Project drilling phase 1997-1999). This groundbreaking project – the only integrated outcrop-subsurface study of a coarse-grained deep-marine system worldwide to date – was funded by a consortium of oil companies under the auspices of the Norwegian Petroleum Directorate (NPD), including Conoco, BP, ExxonMobil, NorskHydro-Statoil, TotalFinaElf and Phillips Petroleum. With funding from other oil companies, the Ainsa Project has continued since the drilling phase until the present time. Research conducted as part of the Ainsa Project has included onshore drilling and coring, detailed sedimentary core logging, seismic acquisition, wireline logging, micropalaeontology and sedimentary petrography.

As part of the post-drilling phase of the Ainsa Project, the UCL DWRG has been and continues to be involved in several industry-sponsored field-based sedimentological and stratigraphic studies:

(i) Investigations of the architecture of the sandy systems in the Ainsa basin, including their thickness, geometry, and lateral and vertical connectivity [1]. Research results included the production of the first detailed geological map for the aerial distribution of the sandy systems, prior to which only sketchy maps were available. This project was sponsored by Shell UK (2002-2010) and ExxonMobil (2007-2012).

(ii) A study of the Guaso system in the Ainsa basin, which found it to be a structurally confined, low-gradient, mainly fine-grained, deep-water system for which, prior to this study, only a very few and poorly documented case studies existed [2]. This work underpins interpretations of the Buzzard Field, northern North Sea, which consists of stacked sandstone reservoirs in a shelf-edge-delta-supplied basin. It was initially sponsored by Shell UK (2005-2010). In 2005, the

UCL DWRG was also involved in an evaluation of the reservoir sandstones, including thin-section work, when the Buzzard Field was first drilled by PanCanadian (now Nexen Petroleum), which in turn led to Nexen Petroleum funding present research by the UCL DWRG.

(iii) Studies of trace fossils in the Ainsa basin and their use in environmental interpretation, something that is invaluable to oil companies looking at limited core material [3, 4]. This work showed that trace fossils are powerful indicators of submarine-fan and related environments. The project was sponsored by BP (2002-2007).

(iv) Study and characterisation of the stratigraphic significance of mass-transport deposits/complexes (MTDs/MTCs) in the Ainsa basin [5, 6]. Such processes and their deposits can cut out reservoir sandstones and provide seals to any hydrocarbon-bearing reservoir sandstones, and their study is therefore of interest to the hydrocarbon industry. Most recently, this work was sponsored by Nexen Petroleum (2010-2014) [5].

3. References to the research

[1] Deconvolving tectono-climatic signals in deep-marine siliciclastics, Eocene Ainsa basin, Spanish Pyrenees: Seesaw tectonics versus eustasy, K. T. Pickering and N. J. Bayliss, *Geology*, 37, 203-206 (2009) doi:10/d6zqfs

[2] End-signature of deep-marine basin-fill, as a structurally confined low-gradient clastic system: the Middle Eocene Guaso system, South-central Spanish Pyrenees, C. Sutcliffe and K. T. Pickering, *Sedimentology*, 56, 1670-1689 (2009) doi:10/ds2vsc

[3] Trace fossils as diagnostic indicators of deep-marine environments, Middle Eocene Ainsa-Jaca basin, Spanish Pyrenees, T. G. Heard and K. T. Pickering, *Sedimentology*, 55, 809-844 (2008) doi:10/fn7rhc

[4] Milankovitch forcing of bioturbation intensity in deep-marine thin-bedded siliciclastic turbidites, T. G. Heard, K. T. Pickering and S. A. Robinson, *Earth & Planetary Science Letters*, 272, 130-138 (2008) doi:10/cf5wtp

[5] Channel-like features created by erosive submarine debris flows: Field evidence from the Middle Eocene Ainsa Basin, Spanish Pyrenees, N. Dakin, K. T. Pickering, D. Mohrig and N. J. Bayliss, *Marine and Petroleum Geology*, 41, 62-71 (2013) doi:10/n4z

[6] Mass-transport complexes (MTCs) and tectonic control on confined basin-floor submarine fans, Middle Eocene, south Spanish Pyrenees, K. T. Pickering and J. Corregidor, *Journal of Sedimentary Research*, 75, 761-783 (2005) doi:10/bx9rdt

References [1], [6] and [5] best indicate the quality of the underpinning research.

Research grants: Between 1994 and 2010, the group received £850,000 from various funders, including Exxon-Mobil, Shell (UK), British Petroleum, BP-Amoco, Chevron, Conoco, Elf, Mobil, Phillips Petroleum, Statoil and Nexen Petroleum UK.

4. Details of the impact

The Ainsa basin is of considerable interest to the hydrocarbon industry because it is an analogue for producing oilfields in deep-marine sandstone reservoirs in hydrocarbon provinces worldwide.

The hydrocarbon companies that participated in the Ainsa Project have been impacted upon by the UCL DWRG's research in three ways between 1 January 2008 and 31 July 2013:

1) UCL research results have been used by oil companies including Chevron, Nexen

Petroleum UK, ExxonMobil and BP to create improved in-house computer-generated hydrocarbon reservoir models aimed at helping with reservoir characterisation and simulation. These improved models allow the companies to manage and develop their reservoirs better, leading to improved company performance.

UCL Ainsa Project results provided hard data on likely reservoir continuity, porosity-permeability, vertical and lateral pathways and baffles to fluid flow, which the participating oil companies use to explore and define levels of uncertainty in their reservoirs. This, in turn, allows them to value their assets and projects better (e.g. calculate volumes of recoverable hydrocarbons), leading to more informed business and investment decisions.

The Head of Stratigraphy at BP noted that the UCL outcrop studies provide the company with data and ideas at a sub-seismic scale, and are therefore critical in their development of a range of alternative in-house models for producing oilfields. He said: “The detailed studies and publication of the work is one of the key elements in allowing us to understand and plan the development of our reservoirs” [A]. The underpinning research is used for the same purpose at ExxonMobil; their Senior Technical Consultant for Hydrocarbon Systems said: “deep-water systems are important reservoirs for our company and research like yours help us explore and develop these resources more effectively” [B].

Nexen Petroleum UK benefits from the research in the same way. Their Lead Geologist for the Buzzard Field said: “The real value in Kevin Pickering’s work and on-going research to Nexen is in the manner we create and populate our reservoir models. His and his student’s Ainsa Basin research provides hard data that we use to define certain levels of uncertainty in our reservoirs. This, in turn, allows us to better value our assets and projects, leading to more informed business and investment decisions” [C].

Similarly, one of Chevron’s Research Geologists said: “Deep-water reservoirs are extremely important for Chevron’s exploration and production, and understanding of the geology is fundamental to their success. Quality outcrop field work, such as is provided by the research group at UCL, is required to provide analogue models, test predictive stratigraphic concepts, and provide key data on sub-seismic heterogeneity that impacts fluid flow in these reservoirs. The research undertaken by UCL in the Ainsa Basin, and the group’s publications have greatly assisted Chevron in this effort” [D].

An example of a hydrocarbon reservoir that has been impacted upon by the UCL DWRG research results is the Buzzard Field in the northern North Sea, which is principally operated by Nexen Petroleum UK [C]. This asset is in its early field life, producing about 200,000 barrels per day (May 2013), and holds enough crude oil to deliver potentially about 10% of the UK's annual forecast oil demand. Reservoir complexity and potential reservoir variability away from well control remain key issues on Buzzard, accounting for significant volumetric uncertainty and representing the primary risk for new drilling opportunities. The new model for the spatial variation of sedimentary lithofacies within reservoir intervals in the Ainsa basin, developed by the DWRG, has directly impacted upon predictions of spatial variation in primary sandstone reservoir quality in the Buzzard Field. Subsequent drilling has corroborated the revised depositional framework in the reservoir intervals. Revisions to the existing lithostratigraphic correlation scheme were therefore made and incorporated into Nexen’s subsequent reservoir model updates for the Buzzard oilfield [C].

2) UCL Ainsa Project research results are used to run in-house training courses at hydrocarbon companies for geologists, geophysicists, reservoir engineers and managers. This training improves understanding amongst company employees and results in them being able to make more informed decisions throughout their careers about how to manage their reservoirs, leading to the companies being able to extract more oil from reservoirs and making more money. The four companies mentioned below ran at least one in-house training course per year during the REF impact period.

At Nexen Petroleum UK, “staff are encouraged to participate in field-courses to the Ainsa Basin,

where UCL's work including the UCL-based Ainsa Drilling project are discussed as it provides a unique dataset allowing workers to compare 1D well data with 2D and near 3D outcrops" [C]. A letter from their Lead Geologist for the Buzzard Field says: "I'm sure anyone who has utilized this data has learnt valuable lessons in subsurface uncertainty" [C].

Over 500 BP subsurface professionals from around the globe have visited the Ainsa basin over the last 15 years to take part in training courses underpinned by the UCL research and have "directly benefited from the UCL studies" [A]. The Head of Stratigraphy noted that because of UCL's "superb dataset" on the outcrops in the Ainsa basin, "these outcrops provide excellent teaching tools, and within BP form the backdrop for regular deepwater exploration and production courses and an annual reservoir modelling course" [A].

Chevron also runs a training course in the Ainsa basin, and "has made extensive use of the research products of the UCL group" [D]. Their Research Geologist said: "the core and wire-line log data collected from behind the outcrop provides a unique teaching aid which can be used to relate subsurface data and well-correlation principles to outcrop observations" [D]. Similarly, ExxonMobil's Senior Technical Consultant noted: "We have an intense training effort in Ainsa and the materials and learnings generated by this program [the Ainsa Project] are a key component of our training" [B].

3) Hydrocarbon companies benefit from the employment of skilled research students from the DWRG. Chevron has employed three Ph.D. students from the DWRG (two in the REF impact period), and is benefiting from the skills acquired by these employees whilst conducting the underpinning research [D]. Ph.D. students from the DWRG have also been employed by ExxonMobil in 2010 [B] and Nexen Petroleum has created internships in 2012 and 2013 for two of the DWRG's current Ph.D. students [C].

5. Sources to corroborate the impact

[A] Supporting statement from Senior Technical Consultant (Hydrocarbon Systems), ExxonMobil – corroborates the impact on reservoir modelling and training at ExxonMobil. Also corroborates the employment by ExxonMobil of DWRG Ph.D. students. Available on request.

[B] Supporting statement from Head of Stratigraphy, BP – corroborates the impact on reservoir modelling and training at BP. Available on request.

[C] Supporting statement from Lead Geologist: Buzzard Field, Nexen Petroleum UK – corroborates the impact on training and reservoir modelling at Nexen Petroleum UK, including modelling of the Buzzard Field reservoir. Also corroborates the creation of internships at Nexen for DWRG Ph.D. students. Available on request.

[D] Supporting statement from Research Geologist (Deep Water Research Group), Chevron Energy Technology Company – corroborates the impact on reservoir modelling and training at Chevron. Also corroborates the employment by Chevron of DWRG Ph.D. students. Available on request.