REF2021

Institution: University of Manchester	

Unit of Assessment: 7 (Earth Systems and Environmental Sciences)	

Title of case study: New geological understanding reducing risk and uncertainty to improve economic exploitation of oil and gas resources across North Africa

Period when the underpinning research was undertaken: 2006 - 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Jonathan Redfern	Professor	2004 – present
Cathy Hollis	Professor	2007 – present
Mads Huuse	Professor	2009 – present
Kevin Taylor	Professor	2011 – present
Stefan Schroeder	Senior Lecturer (2019 – present) Lecturer (2011 – 2019)	2011 – present
Emma Finch	Senior Scientific Officer	2008 – present
David Hodgetts	Reader (2019 – present) Senior Lecturer (2004 – 2019)	2004 – present

Period when the claimed impact occurred: August 2013 – July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

The oil and gas industry has benefited from increased success and efficiency in oil exploration and development through University of Manchester research. The industry is currently responsible for over 50% of global energy needs, and in 2020 was valued at USD86Trillion. Exploration wells range in cost from 10s to 100s million USD, and the risk associated with such investments has been reduced through better information and new research concepts that inform company decision making.

The understanding of outcrop and subsurface geology and interpretation of geophysical data, has been advanced by new data collected from northern Africa to develop evaluation models. The results have been utilised by 22 international oil companies (including Repsol, BP, and Petroceltic) to improve prediction of where to explore for oil and gas resources in North Africa, thus reducing uncertainty and risk, and also impacted the appraisal and development of oil and gas fields. This research has facilitated more targeted use of resources concerning multi-million-dollar decisions for exploration and development. This work has also built capacity within national government bodies in North Africa, through guided professional development and training of their geoscientists.

2. Underpinning research

In relation to oil extraction, many areas of North Africa are under-explored and have energy poverty, or only have geological studies of small areas, with limited research that lacks larger scale regional context. The North Africa Research Group (NARG) at the University of Manchester (UoM) has been undertaking geological research since 2000 to address this limitation. The NARG comprises collaboration between UoM (the lead partner and where most research is undertaken), Heriot Watt University and TuDelft University. It was founded in 2000 and is led by Prof Jonathan Redfern at UoM, and collaborates with international academic and industry partners. This enables industry sponsors to ensure the research is of direct value and benefit.

The UoM-led research has two distinct scales:

Regional basin-scale (>> 10km):
This body of work evaluates basin structural evolution and depositional systems over a regional scale (defined as far greater than 10km), based on combined structural and sedimentological analysis, including the evolution of sediments during burial and diagenesis. The research involves biostratigraphic studies that have resulted in new stratigraphic frameworks [1] with implications for regional correlation. This research has also advanced understanding on the structural evolution of basins, including developing new models to interpret the complex control salt structures that affect both sedimentation and trapping configurations [2]. These models address the mechanism that controlled the salt geometry and evolution, with important implications for mapping sea floor topography at the time of reservoir deposition. New conceptual models have also been delivered for basin evolution and fluid migration and mapping depositional systems and palaeogeographies across NW Africa [3]. This yielded new models for the timing of hydrocarbon charge and its impact on reservoir quality, explaining the distribution of good and poor reservoirs in the Ain Tsila field, a model that has wider implications for similar inverted basin settings. UoM research also developed models for key depositional systems, with implications for organic enrichment of mudrocks, to enable the prediction of regional distribution of hydrocarbon source rocks [4], as well as modelling the characterisation of reservoir rocks [3, 5] and their porosity and permeability distribution [3, 6].

Field scale (1 to 10s of km):
This body of research determines the distribution and quality (porosity and permeability) of reservoir rocks that control the storage and flow of hydrocarbons in oil and gas fields. This is undertaken through geological analysis and imaging of outcrops, integrated with subsurface core and electrical log data, microscopic observation and low temperature geochemistry. UoM research generated models that predict reservoir distribution and quality [3, 5, 6]. For the first time, this enabled the reservoir properties of wells in the Ain Tsila field in Algeria to be predicted. This developed new concepts both for the evolution of the Ain Tsila structure, but also fluid flow within the basin and basin charge during exhumation.

3. References to the research

UoM authors are denoted in **bold.** Citation counts are from Web of Science (November 2020).

[1] **Luber, T.L., Bulot, L.G., Redfern, J.,** Nahim, M., Jeremiah, J., Simmons, M., Bodin, S., Frau, C., Bidgood, M. and Masrour, M. (2019) A revised chronostratigraphic framework for the Aptian of the Essaouira-Agadir Basin, a candidate type section for the NW African Atlantic Margin. *Cretaceous Research*, **93**, p.292-317. DOI:10.1016/j.cretres.2018.09.007 (6 citations)

[2] **Muniz-Pichel, L., Huuse, M., Redfern, J.,** and **Finch, E.** (2019) The influence of base-salt relief, rift topography and regional events on salt tectonics offshore Morocco. *Marine and Petroleum Geology*, **103,** 87-113, DOI: 10.1016/j.marpetgeo.2019.02.007 (5 citations)

[3] **English, K. L.,** English, J. M., Bonnell, L. M., **Redfern, J.,** Lander, R. H., **Hollis, C.,** and Yahia Cherif, R. (2017) Controls on reservoir quality in exhumed basins – an example from the Ordovician sandstones, Illizi basin, Algeria. *Marine and Petroleum Geology,* **80**, 203-227. DOI:10.1016/j.marpetgeo.2016.11.011 (8 citations)

[4] **Bodin, S., Fröhlich, S.,** Boutib, L., S Lahsini, S., and **Redfern J.** (2011) Early Toarcian Source-Rock Potential in the Central High Atlas Basin (Central Morocco): Regional Distribution and Depositional Model. *Journal of Petroleum Geology* **34** (4), 345-363. DOI:10.1111/j.1747-5457.2011.00509.x (25 citations)

[5] **Mader, K, N., Redfern, J.**, Ouataoui M. (2017) Sedimentology of the Essaouira Basin (Meskala Field) in context of regional sediment distribution patterns during upper Triassic pluvial events. *Journal of African Earth Sciences*, **130**, 293-318 DOI: 10.1016/j.jafrearsci.2017.02.012 (5 citations)

[6] **Newport, R., Hollis, C., Bodin, S.** and **Redfern, J.** (2017) Examining the interplay of climate and low amplitude sea-level change on the distribution and volume of massive dolomitisation: Zebbag Formation, Cretaceous, Southern Tunisia. *The Depositional Record,* **3**(1), 38-59, DOI:10.1002/dep2.25 (3 citations)

4. Details of the impact

Context

Oil and gas exploration and development is economically important. It provides a critical source of global energy and chemical feedstock. In developing countries finding indigenous resources is a high priority given they often have severe energy poverty, and must use a significant proportion of their GDP to import oil and gas. In 2020, the industry was responsible for over 50% of global energy needs, with demand expected to remain at similar levels until 2030/40, even assuming an ambitious rate of energy transition to renewables. The industry is currently valued at USD86trillion. There is continued demand from oil companies to maximise the efficiency of operations and reduce risks of either drilling and not finding economic resources, or not being able to efficiently extract the maximum resource from a discovery.

Pathway to impact

NARG's research includes both fundamental science and applied research to meet specific industry challenges. Companies that sponsor NARG, as well as collaborating government bodies, have direct access to this research through a restricted online portal [A]. Broad research aims are developed in collaboration with sponsors through regular steering group meetings to ensure the research addresses the most pressing user issues. Results are shared through technical presentations, workshops, field courses, and publications as well as the extensive NARG GIS database [B]. These data allow companies to recognise opportunities for exploration and ultimately to make decisions on where to drill exploration wells or whether they should downgrade areas for further work. The information also helps de-risk in-place volume and recoverable resource estimates and impacted field development planning, such as where to site wells to optimize field planning.

Impact on exploration – improvement to operational decisions and reduced financial risk

Regional fieldwork and integration with subsurface data, associated with data analysis of outcrop and subsurface samples, has enhanced regional models and aspects of key interval dating through improved biostratigraphy [1] and source rock development [5], both critical for any petroleum system evaluation. This has impacted on companies' assessment of the prospectivity of acreage, by locating and characterizing potential hydrocarbon source rocks, and improving modelling of their thermal maturity and ability to generate oil or gas. Other examples of models derived from this research include better-defining ancient river systems, thus enabling improved accuracy in predicting the location and quality of sandstone reservoirs in the subsurface [4]. [Text removed for publication].

Exploration wells range in cost from 10s to 100s million USD, with overall exploration and development budgets in the order of 100s of million USD. Such investments are high risk, and the overall impact of this research was to successfully reduce this risk by providing better information on which companies would base their decisions.

The NARG web-based GIS database [B], which was developed in 2018 and incorporates the entire Group's research outputs, allows an easily accessible and effective resource for corporate knowledge dissemination and facilitates improvements to operational decisions within the sponsor companies. This database was designed to allow geoscientists to

confidently understand more the regional geology and characteristics of key reservoir or source intervals, aid subsurface predictions and reduce uncertainty. The research projects including [1] and [5], involved outcrop studies that enabled UoM to record direct field measurements that translated into modelled interpretations, to assist with operational decisions. This includes interpretations on depositional environments, thermo-chronology from logged sections, and new biostratigraphic faunal descriptions [1]. [Text removed for publication].

The data have been, and continue to be, used by companies to screen acreage and develop understanding of the prospectivity of basins and parts of basin, to develop new concepts for targets to drill, and evaluate risk and uncertainty during exploration and development, and appraisal strategies. [Text removed for publication].

Impact on oil field development – improved operating costs
The UoM field scale research of the Ain Tsila field (Morocco) assessed reservoir quality distribution and examined both regional and local controls using an integrated suite of digital and rock data [3]. [Text removed for publication]. As a result of this research, uncertainty of oil well performance was reduced, lowering the financial risk associated with otherwise drilling low productivity wells and thereby contributing to an increase in profitability.

Impact on national exploration capacity and delivery of training in North Africa
Through targeted engagement, NARG have built close collaboration with government agencies and universities in North Africa. Since 2002, UoM have regularly provided staff training and access to field-based courses and workshops, thus improving staff capability and competence to make decisions. In Morocco, there is a longstanding relationship between NARG and ONHYM [B], enabling knowledge exchange, research publications, and the new GIS Database [D], with 7 ONHYM staff directing attending training courses since 2013. This has had a continuing positive impact on national capacity to internally assess the petroleum potential of Morocco, improve their capability to undertake independent studies, and to critically assess work undertaken by international oil companies. In 2018, NARG commenced similar activities in Senegal with Petrosen, undertaking 1 workshop for industry and academia, and running a training programme at the University of Dakar (UCAD).

5. Sources to corroborate the impact

[A] www.narg.org.uk Main group website with publicly accessible information, images and models
[B] Password-protected GIS database available for sponsoring companies hosted on www.narg.org.uk
[C] Letter of support from Team Leader Exploration North Africa, Repsol, January 2020
[D] Letter of support from Director General, ONHYM (Organisation National Hydrocarbure et Minerals Morocco) Government organisation, January 2020
[E] Letter of support from Senior Geoscientist, Chevron, January 2020
[F] Letter of support from Mauritania and Senegal Exploration Manager, BP, January 2020
[G] Letter of support from Director, Europa Oil and Gas Ltd (Petroceltic), January 2020