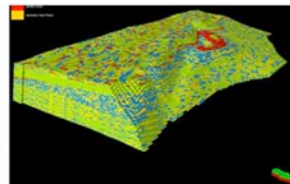
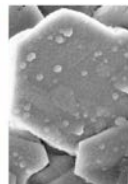




North Africa Research Group (NARG)

2019

www.narg.org.uk



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1. Background: The **North Africa Research Group (NARG)** was founded in 2000 and conducts multi-disciplinary research with a petroleum geoscience theme in northern Africa. Current focus has been on Morocco, Algeria, Egypt, Libya and Tunisia. The research includes projects with integrated sedimentology, geochemistry, seismic interpretation, petrophysics and reservoir engineering. The group involves collaboration between Manchester and TuDelft Universities, all of whom have an established record of petroleum geoscience and engineering research, supported by a group of international oil companies with the desire to promote research in this area.

2. Academic Institutions: The Research group is housed at the University of Manchester, where the majority of the researchers are currently based. Research is carried out by the Universities of Manchester, Heriot Watt University and TuDelft, together with research partner institutions. The group is led by **Prof Jonathan Redfern**.



3. Current sponsors of the research group: BP, Repsol, Cairn, Equinor, ENI, Total, Hunt Oil and Shell (correct as of 1/2/2019). A number of these sponsors joined the group at its foundation.



4. Membership: Sponsors join for a period of 3 years, which can subsequently be renewed on an annual basis or for further 3-year periods.

5. Facilities: the research group has access to world-class facilities at the collaborating Universities. This includes full geochemical and sedimentological laboratories, with SEM, XRD, Ion probe and noble gas mass spectrometers, cold cathodoluminescence, UV fluorescence microscopes and fluid inclusion stages. Comprehensive analytical geochemistry facilities including: ICP-MS, ICP-AES, XRF, XRD, pyrolysis, GC-MS. Manchester also has analytical rigs for rock mechanics. Both Manchester, TuDelft and Heriot Watt have modern petrophysical suites. NARG also has a dedicated field GR, portable core drilling, LIDAR and DGPS. The group has access to a full suite of industry standard software including Schlumberger Petrel, VRGS, RocDoc, Oasis Montaj, MatLab, Zetaware, Genex and TemisPak, Petromod, 2D and 3D Move. The University of Manchester has the largest workstation suite in the UK, with 80 seat, double screen high spec PCs, all with full Petrel and Schlumberger licences.

6. Research Themes: The North Africa Research Group undertakes a wide range of research projects, as PhDs, PostDoctoral Research Projects or shorter studies. The research themes are decided by the Steering Committee, which meets twice a year. They are agreed by consensus and reflect the broad research interests of the sponsor companies and universities. Companies are encouraged to be involved in the studies, by providing data, supporting the students in the field, providing internships for the PhDs and participation in workshops that are held on a regular basis.

7. Confidentiality: Any data provided by a sponsor company is held under strict confidentiality, as outlined in the Sponsor Contract. This data will not be shared or seen by other sponsors unless explicit permission is granted. The research results and interpretation are provided to all sponsors (maps etc). Original data may only be provided if permissions are received from the donor company. Permission is sought prior to any publication that includes confidential data.

8. Publication Policy: The aim of the group is to publish all research in leading academic journals. Companies gain access to these results in advance as the research progresses, and also receive pre-prints of all papers. Companies can also access all the interpreted data and field data, subject to availability (sample size etc).

9. Data / GIS Database: All data collected in the field, and all interpreted data is made available to the

sponsor companies. Field locations are currently being incorporated into a **Web Accesible GIS database**, which is provided to all sponsors.

10. Workshops and Field courses: NARG undertakes workshops, both in sponsors company offices and workshops open to the wider academic and industry community. Dedicated field courses are also organised for training. Past courses have been held in Morocco and Canada for sponsor companies (see appendix for details)

11. Conferences: Full acknowledgment is given to the sponsor companies on any presentations made by the research group. The group aims to present research at all leading conferences.

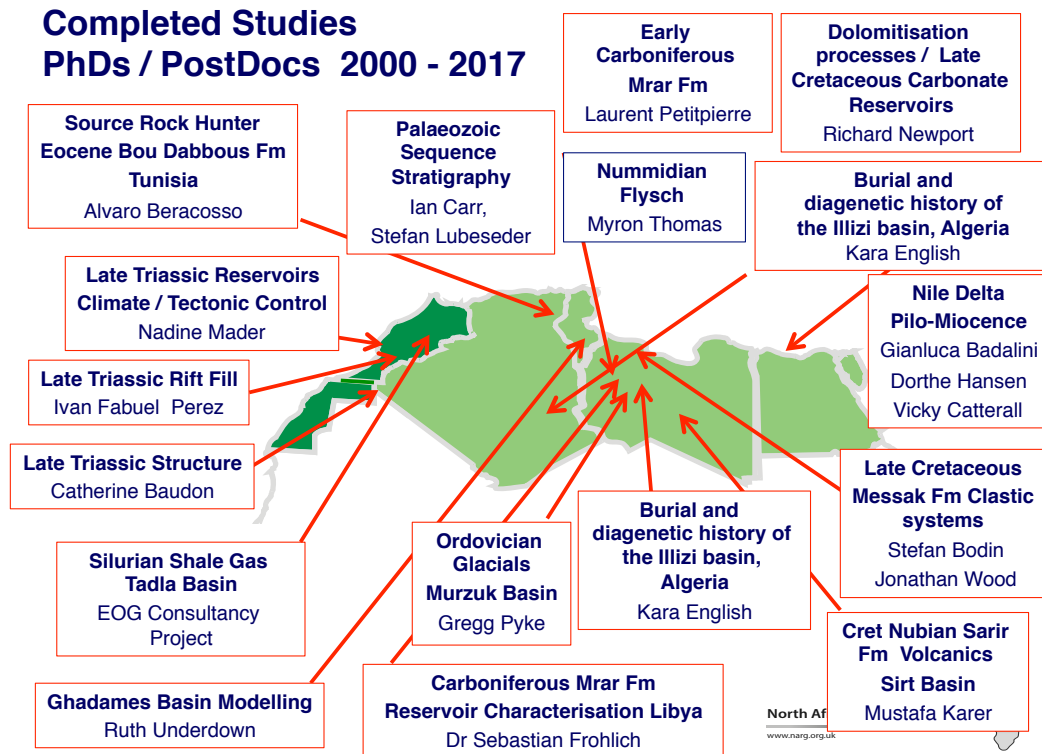
12. Researchers: Research is undertaken by academic staff at the host Universities (a full list is provided in section 17), who also support and supervise a number of PhDs and Postdoctoral researchers. Currently (January 2019) the research group directly funds **4 PhDs:** Aude Duval-Arnould, Emmanuel Roquette, Orrin Bryers, James Lovell Kennedy fully funded by NARG, and 2 PhD who are partially funded by NARG on related North Africa projects: Jianpeng Wang (Chinese Gov. Scholarship), Nawar Al-Sinawi funded on a PDO Scholarship. In addition we have 1 Postdoc Dr Remi Charton, 3 Research Assistants and 1 GIS Administrator.

A further 3 PhD are expected to commence this year and 1 additional PostDoc.

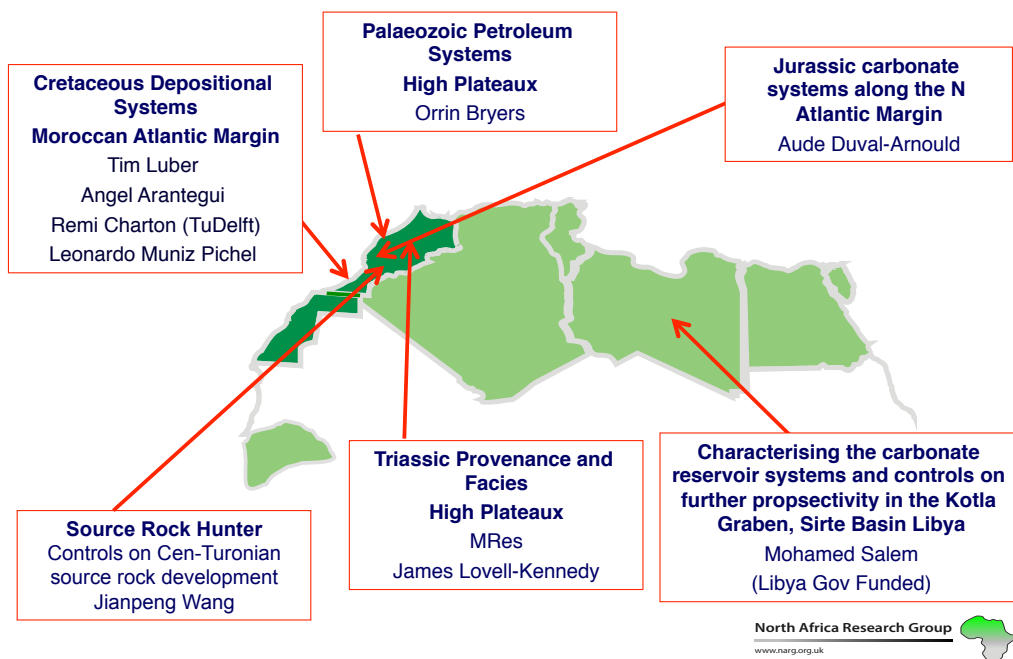
13. Links to African Institutions: The North Africa Research Group has established strong links with universities and government organisations in North Africa, including ONHYM in Morocco, LPI and NOC in Libya, Alnaft in Algeria and Petrosen in Senegal.

14. Research Projects

A summary of completed research projects is shown on the attached figures:



Completed Studies 2017 - 18



15. Completed Research Projects: The group has completed a number of major regional studies across North Africa:

- 14.1 Third order sequence stratigraphic framework for the Palaeozoic reservoirs of North Africa
- 14.2 Petroleum generation and migration in the Ghadames Basin, north Africa: A two-dimensional basin-modeling study
- 14.3 Depositional systems, stratigraphy and reservoir characterisation of the Early Cretaceous of Libya and Tunisia.
- 14.4 Early Carboniferous – Marar Formation and overlying Assedjefar FM, Ghadames Basin Libya
- 14.5 Nummidian Flysch depositional system and provenance
- 14.6 Late Triassic Syn-Rift Sequences – High Atlas, Argana Basin and Fundy Basin, Nova Scotia.
- 14.7 Deepwater Slope Channel and Mass Flow Complexes, Nile Delta
- 14.8 Ordovician Glaciogenic Reservoir Systems, Murzuk Basin, Libya
- 14.9 Source Rock Hunter Project and Basin Modelling
- 14.10 Carbonate Reservoir Studies: Dolomitisation of Late Cretaceous Reservoirs, North Africa and Spain
- 14.11 FRAC -Fractured Reservoir Analogues Carbonates
- 14.12 Diagenesis and thermal history of the Illizi Basin during the Ordovician, Algeria
- 14.13 Characterisation of Cretaceous Depositional Systems along the Atlantic Passive Margin, Morocco – A source to sink study
- 14.14 Jurassic Carbonate reservoir architecture, evolution and characterisation: Atlantic Margin
- 14.15 Source Rock Hunter: Controls on distribution and quality of the Turonian / Cenomanian Source rocks along the Atlantic Margin
- 14.16 Controls on carbonate reservoir development, Kotla Graben, Sirt Basin, Libya.

14.1 Third order sequence stratigraphic framework for the Palaeozoic reservoirs of North Africa

This study was undertaken by Stefan Lubeseder, supervised by Prof Jonathan Redfern. The aim was to develop a third-order sequence stratigraphic framework for the Silurian and Devonian of North Africa, focusing on Morocco, Algeria, Tunisia and Libya. Due to the stability of the Saharan Craton during this period, Palaeozoic stratigraphy is relatively uniform across the area, allowing a regional study. Palaeozoic rocks form important reservoir and source rocks in North Africa, from the Cambrian to the Carboniferous. A sequence stratigraphic scheme together with the geometry of depositional systems and the key characteristics of their boundaries was developed, which offers as a valuable tool for the prediction of reservoir units in areas beyond data control. The outcrop studies can also serve as analogues to reservoir units in the subsurface. The final PhD thesis contain large inter-regional chronostratigraphic correlation charts, constructed to illustrate the intracratonic depositional model for North Africa. Practically, the study was split into three parts:



Morocco field case study:

Silurian: Silurian sections were studied in the Tafilalt area as well as in the Dra Plain of southern Morocco (Anti-Atlas). The emphasis was on the Ludlowian “*Orthoceras*” limestones and the so-called “*Scyphocrinites*” limestones at the Silurian/Devonian boundary. These limestone levels were studied in terms of their biostratigraphic position, depositional system, and inter-regional sequence stratigraphic significance. Silurian “*Orthoceras*” limestones are known from various other parts of the world and the study provided a significant contribution to the understanding of these beds.

Publications:

Lubeseder, S. (2008). Palaeozoic low-oxygen, high-latitude carbonates: Silurian and Lower Devonian nautiloid and scyphocrinoid limestones of the Anti-Atlas (Morocco). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 264(1-2): 195-209

Lubeseder, S., Redfern, J., Boutib, L., (2009), Mixed siliciclastic-carbonate shelf sedimentation- Lower Devonian sequences of the SW Anti-Atlas, Morocco Source: *Sedimentary Geology*, 215, 1-4, pp. 13-32

Lubeseder S., J. Redfern, L. Petitpierre, S. Fröhlich. (2011). Stratigraphic trapping potential in the Carboniferous of North Africa: developing new play concepts based on integrated outcrop sedimentology and regional sequence stratigraphy (Morocco, Algeria, Libya). *Geological Society, London, Petroleum Geology Conference series 2011*, v. 7, p. 725-734, doi: 10.1144/0070725

PhD Thesis:

Stefan Lubeseder 2005: Silurian and Devonian Sequence Stratigraphy of North Africa: Regional Correlation and Sedimentology (Morocco, Algeria, Libya)

14.2 Petroleum generation and migration in the Ghadames Basin, north Africa: A two-dimensional basin modeling study

The Ghadames Basin contains important oil- and gas-producing reservoirs distributed across Algeria, Tunisia, and Libya. Regional two dimensional (2-D) modeling, using data from more than 30 wells, was undertaken to assess the timing and distribution of hydrocarbon generation in the basin. Four potential petroleum systems have been identified: (1) a Middle–Upper Devonian (Frasnian) and Triassic (Triassic Argilo Greyseux Inferieur [TAG-I]) system in the central-western basin; (2) a Lower Silurian (Tanezzuft) and Triassic (TAG-I) system to the farwest; (3) a Lower Silurian (Tanezzuft) and Upper Silurian (Acacus) system in the eastern and northeastern margins; and (4) a Lower Silurian (Tanezzuft) and Middle–Upper Devonian (Frasnian) system to the east-southeast. The results indicated that the Lower Silurian Tanezzuft source rock underwent two main phases of hydrocarbon generation. The first phase occurred during the Carboniferous, and the second started during the Cretaceous, generating most hydrocarbons in the eastern (Libyan) basin. The Frasnian shales underwent an initial, minor generative phase in the central depression during the Carboniferous. However, the main generation occurred during the Late Jurassic–Cenozoic in the western and central depression.

The Frasnian shales are currently only marginally mature in the eastern part of the basin. Modeling indicated that the Alpine (Eocene) exhumation of the eastern (Libyan) basin margin had a significant control on the timing of hydrocarbon generation from the Lower Silurian source rock. The preferred burial-history model calibrates source rock maturity data by incorporating late exhumation and reduced subsidence

PhD: Ruth Underdown supervised by Prof Jonathan Redfern

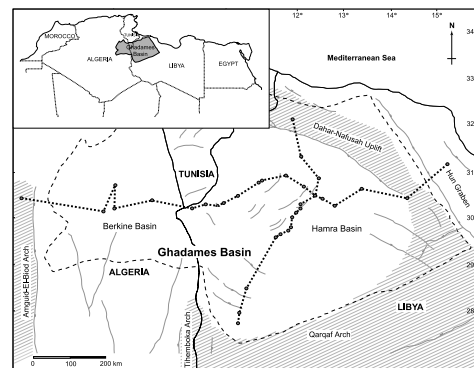
Publications:

Underdown, R., and Redfern, J., (2007), The importance of constraining regional exhumation in basin modelling: a hydrocarbon maturation history of the Ghadames Basin, North Africa., *Petroleum Geoscience*, V 13, 1-19

Underdown, R., and Redfern J., (2007), Constraining the burial history of the Ghadames Basin, North Africa: An integrated analysis using sonic velocities, vitrinite reflectance data and apatite fission track ages. *Basin Research*, Volume 19, Number 4, 557-578(22)

Underdown, R., and Redfern, J., (2008), Petroleum Generation and Migration in the Ghadames Basin, North Africa: A 2D Basin Modelling Study, *AAPG Bulletin*, V. 92, No. 1 , 53-76

PhD Thesis: Ruth Underdown



14.3 Depositional systems, stratigraphy and reservoir characterisation of the Early Cretaceous of Libya and Tunisia.

The project commenced in 2006 with a PhD undertaken by Mustafa Karer and supervised by Prof Jonathan Redfern, and was extended to include a field based study led by Dr Stephan Bodin and Prof Jonathan Redfern, with PhD student Jonathan Wood. This involved extensive fieldwork in the Murzuk Basin Libya and along the Jeffara Arch (Libya and Tunisia). The research involved collaboration with the LPI Libya and University of Sphax, Tunisia. Aims were to understand the evolving depositional systems, revise the stratigraphy /sequence stratigraphy and characterise /evaluate potential Early Cretaceous reservoirs. The study extended to the subsurface in the Sirt basin, where the "Nubian" sandstones are one of the main reservoir targets. This phase was completed in 2012, with a series of publications and the successful completion of Jonathan Woods PhD. This project may be extended in future to incorporate further subsurface data, and extend to Egypt and the wider region.

The separate but linked project undertaken by Mustafa Karer (funded by the Libyan government / LPI, with data sponsored by Wintershall) examined the Nubian sandstone and associated igneous activity in the Hameimat Trough, Sirt Basin, Libya. The research utilized high-resolution 3D seismic data, combined with gravity, aeromagnetic, well data and cuttings samples. This project provides valuable insight into seismic imaging of intrusive and extrusive igneous events within the Nubian (Sarir Sandstone) in the Sirt basin, Libya. The presence of volcanics can prove a hazard to drilling, and of emplacement volcanics can have serious detrimental effects on reservoir volume and quality. A number of major oil fields in eastern Sirt basins produce from the Early Cretaceous Nubian sandstone. This significant reservoir is highly structured and has a poorly understood facies distribution. As drilling targets deeper reservoirs or more complex structural areas, developing a better understanding of the Nubian is crucial to successful future exploration. In some localities the Nubian contains significant interbedded volcanics, which have affected and often degraded reservoir quality. The volcanics also affect the seismic response and this makes the exploration program very challenging.

Publications:

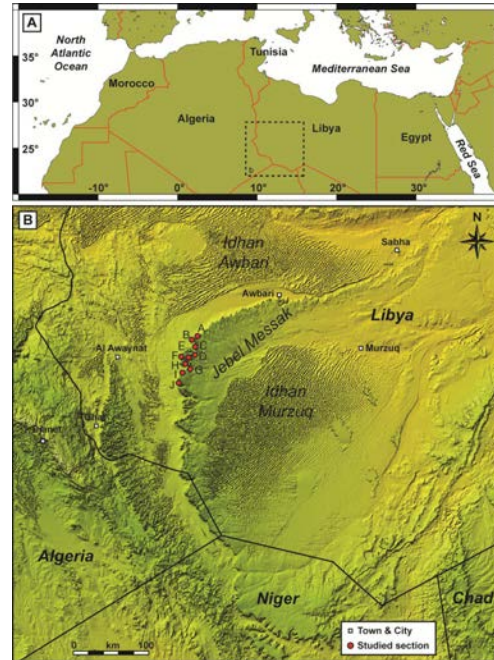
Bodin, S., Wood, J., Petitpierre, L., Redfern, J. (2010). " *Timing of Early to Mid-Cretaceous tectonic phases along North Africa: New insights from the Jeffara escarpment (Libya-Tunisia).*" *Journal of African Earth Sciences* 58, 3. pp 489-506.

Wood, J.D., S. Bodin, J. Redfern, M.F.H. Thomas, (2014), Controls on facies evolution in low accommodation, continental-scale fluvio-paralic systems (Messak Fm, SW Libya), *Sedimentology* V 301 p49-69.

PhD Theses:

2009: Mustafa Karer (now with Haliburton Libya): Nubian Sandstones, Hameimat Trough, Sirte Basin Libya, Evaluating the sedimentology, reservoir characteristics and distribution, and the interbedded igneous units, their origin, distribution and impact on reservoir quality. Libya Gov. Funded

2012 Jonathan Wood (now with Shell International): Sedimentological characterization and regional palaeo-environmental implications of the Messak Fm, SW Libya. NARG Sponsored



14.4 Early Carboniferous – Marar Formation and overlying Assedjefar FM, Ghadames Basin Libya

The project commenced in 2008 and was led by Dr Sebastian Frohlich (now at Equinor and Prof Jonathan Redfern, with PhD student Laurent Petitpiere, following an earlier pilot study carried out by Dr Stefan Lubeseder. The project involved extensive fieldwork in Libya on the southern margin of the Ghadames Basin (in part supported by Woodside). Results provide valuable new insights into the depositional environments, and have identified a series of significant incised valleys in the Carboniferous, possible reservoir targets in the subsurface. The work address the

underlying controls on the system, and refines outcrop to subsurface correlation. In future the project could be extended into the subsurface in Algeria, where these units may offer significant reservoir potential.

Publications:

Fröhlich S., J. Redfern, L. Petitpierre, J. Marshall, M. Power, P. Grech (2009), Diagenesis and reservoir quality evolution of Lower Carboniferous fluvial channels, western Libya) . Journal of Petroleum Geology

Fröhlich, S., Petitpierre, L., Redfern, J., Grech, P., Bodin, S., Lang, S. (2010). "*Sedimentological and sequence stratigraphic analysis of Carboniferous deposits in western Libya: recording the sedimentary response of the northern Gondwana margin to climate and sealevel changes.*" Journal of African Earth Sciences 57 (4), pp. 279-296

Lubeseder S., J. Redfern, L. Petitpierre, S. Fröhlich. (2011). Stratigraphic trapping potential in the Carboniferous of North Africa: developing new play concepts based on integrated outcrop sedimentology and regional sequence stratigraphy (Morocco, Algeria, Libya). *Geological Society, London, Petroleum Geology Conference series 2011, v. 7, p. 725-734*, doi: 10.1144/0070725

PhD Thesis:

2012 Laurent Petitpierre (now with Statoil): Sedimentology and Stratigraphy of the Early Carboniferous Marar Formation in Western Libya. NARG sponsored.

Reports: Preliminary Evaluation of the Carboniferous interval: Dr Stefan Lubeseder pilot study

14.5 Nummidian Flysch depositional system and provenance

The Nummidian Flysch is the most widespread tectono-stratigraphic unit in the western Mediterranean. It outcrops in the Alpine nappe belt, in southern Spain, Morocco, Algeria, Tunisia, Sicily and southern Italy. In Sicily and Tunisia it is an Oligocene to mid-Miocene flysch-type deposit sourced from the north-African passive margin and deposited into an east-west trending foreland basin. This study was supervised by Dr Stephane Bodin and Prof Jonathan Redfern, and undertaken as a PhD by Myron Thomas (now Shell). The study focused on outcrops in northern Sicily and Tunisia, evaluating the sedimentology and provenance within the context of the basin as a whole. Special emphasis is placed upon the controls on deposition and provenance of the clastic supply, which until this study were largely unknown. Future work is intended to extend this study to the west into Algerian and Morocco.

Publications:

Thomas, M. F. H., Bodin, S., Redfern, J., Irving, D. H. B. (2010). "*A constrained African craton source for the Cenozoic Nummidian Flysch: Implications for the palaeogeography of the western Mediterranean basin.*" Earth Science Reviews 101, 1. pp 1-23.

Thomas, M.F.H., S. Bodin, J. Redfern Comment on European provenance of the Nummidian Flysch in northern Tunisia'by Fildes et al.(2010) Terra Nova 22 (6), 501-503

Lubeseder S., J. Redfern, L. Petitpierre, S. Fröhlich. (2011). Stratigraphic trapping potential in the Carboniferous of North Africa: developing new play concepts based on integrated outcrop sedimentology and regional sequence stratigraphy (Morocco, Algeria, Libya). *Geological Society, London, Petroleum Geology Conference series 2011, v. 7, p. 725-734*, doi: 10.1144/0070725

PhD Thesis:

2011: Dr Myron Thomas (now with Shell International): Sedimentology of the Nummidian Flysch – NARG Sponsored

14.6 Late Triassic Syn-Rift Sequences – High Atlas, Argana Basin and Fundy Basin, Nova Scotia.

These projects were run as a lead collaborator in the Atlantic Triassic Project, combining the research power of the Universities of Manchester, Aberdeen and UCD Dublin (Prof Pat Shannon). NARG researchers were Nadine Mader (PhD completed 2008, currently with Maersk) and Ivan Fabuel Perez (PhD completed 2009 currently with Exxon) and Xavier Van Lanen (funded by Shell and currently with Statoil). Academic staff from NARG working on this project

included Prof Jonathan Redfern, Dr David Hodgetts and Prof Brian Williams. Dr Cat Baudon worked on the project as a PostDoc at Manchester, and the students were also supported by Dr Sophie Leleu from Aberdeen University. This involved an integrated analysis of Late Triassic rift sequences in Canada, Morocco and the North Atlantic (and seismic data from Norway and W Britain). Manchester led the research use of LIDAR and field sedimentology in Morocco, characterising reservoirs in the systems, and also looking at the structural controls using field based analysis in the High Atlas of Morocco, the Argana Basin Morocco and Fundy Basin Canada. A number of publications have come out from this research.

Publications:

Redfern, J., Hodgetts, D. & Fabuel-Perez, I. (2007). Digital analysis brings renaissance for petroleum geology outcrop studies in North Africa. In: *First Break* 25, pp. 81-87.

Fabuel-Perez, I., Hodgetts, D., & Redfern, J., (2009), A new approach for outcrop characterization and geostatistical analysis of a low-sinuosity fluvial-dominated succession using digital outcrop models; Upper Triassic Oukaimeden Sandstone Formation, central High Atlas, Morocco *AAPG Bulletin*, 93, 6, pp. 795-827

Fabuel-Perez, I.; Redfern, J.; Hodgetts, D., (2009), Sedimentology of an intra-montane rift- controlled fluvial dominated succession: The Upper Triassic Oukaimeden Sandstone Formation, Central High Atlas, Morocco, *Sedimentary Geology*, v. 218, iss. 1-4, pp. 103-140.

Baudon, C., Fabuel-Perez, I. and Redfern, J. (2009). "Structural style and evolution of a Late Triassic rift basin in the central High Atlas, Morocco; controls on sediment deposition." *Geological Journal*, 44(6): pp. 677-691.

Van Lanen, X.M.T., Hodgetts, D., Redfern, J., Fabuel-Perez, I. (2009). " *Applications of digital outcrop models; two fluvial case studies from the Triassic Wolfville Fm., Canada and Oukaimeden Sandstone Fm., Morocco.*" *Geological Journal*, 44(6): 742-760.

Fabuel-Perez, I., Hodgetts, D. and Redfern, J. (2010). " *Integration of digital outcrop models (DOMs) and high resolution sedimentology; workflow and implications for geological modelling; Oukaimeden Sandstone Formation, High Atlas (Morocco).*" *Petroleum Geoscience*, 16, 133-154.133-154.

Redfern, J., Shannon, P.M., Williams, B.P.J., Tyrell, S., Leleu, S., Fabuel Perez, I., Baudon, C., Stolfova, K., Hodgetts, D., Speksnijder, A., Haughton, P.D.W, Daly, J.S. , (2011) An integrated study of Permo-Triassic basins along the North Atlantic passive margin: implication for future exploration. *Geological Society, London, Petroleum Geology Conference series*, v. 7, p. 921-936, doi: 10.1144/0070921

Mader, N. K. and Redfern, J. (2011). A sedimentological model for the continental Upper Triassic Tadrart Ouaou Sandstone Member: recording an interplay of climate and tectonics (Argana Valley; South-west Morocco), *Sedimentology*, 1365-3091 DOI: 10.1111/j.1365-3091.2010.01204.x

Baudon, C., Redfern, J & Van Den Driessche P; J, (2012), Permo-Triassic structural evolution of the Argana Valley and implications on the kinematics and impact of the Atlantic rifting in the High Atlas, *Journal of African Earth Sciences*, 65, 91-104.

Rarity, F. X. M. T. van Lanen, D. Hodgetts, R. L. Gawthorpe, P. Wilson, I. Fabuel-Perez, and J. Redfern (2013), LiDAR-based digital outcrops for sedimentological analysis: workflows and techniques. Geological Society, London, Special Publications, 387, doi:10.1144/SP387.5

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. *Sedimentology*, doi.org/10.1016/j.jafrearsci.2017.02.012

PhD Theses:

2006: Dr Nadine Mader (now working for Maersk): Sedimentology, third order sequence stratigraphy and controlling factors on facies distribution in the Triassic of North Africa. NARG Funded

2009: Dr Ivan Fabuel Perez (now in Exxon): 3D Modelling of Late Triassic Continental mixed fluvial systems; integrating LIDAR with high resolution sedimentology of fluvial facies: High Atlas, Morocco NARG Funded

2011: Dr Xavier Van Lanen (now with Statoil): Quantitative Outcrop Analysis / Integrated Reservoir Modelling of Triassic Fluvial Facies, Minas Basin, Nova Scotia, Canada. Shell International funded.

14.7 Deepwater Slope Channel and Mass Flow Complexes, Nile Delta

This research was undertaken by PhD student Victoria Catterall, supervised by Prof Jonathan Redfern and Prof Rob Gawthorpe. PostDoc researcher Dr Dorthe Hansen (now Statoil) also contributed to the work. This project studied deepwater depositional processes, controls and evolution of the Nile Delta, Egypt, in the context of submarine channel evolution, and generation and interaction with mass-transfer-complexes. It utilized an extensive 3D database provided by BG Group. This work was undertaken within a sequence stratigraphic framework, with the results providing new and important quantification of the slope system evolution in terms of architecture, structure and morphology.

Publications:

Catterall, V., Redfern, J., Gawthorpe, R.L., Hansen, D.M & Thomas, M.H.F (2010), Architectural Style and Quantification of a Submarine Channel-Levee Systems located in a structurally complex area: Offshore Nile Delta, *Journal of Sedimentary Research*, v. 80; no. 11; pp. 991-1017; DOI: 10.2110/jsr.2010.084

PhD thesis:

2010: Dr Victoria Catterall (now with ExxonMobil): Evolution and morphology of deepwater channels, offshore Nile Delta, Egypt. NERC / BG Group Case funded

14.8 Ordovician Glaciogenic Reservoir Systems, Murzuk Basin, Libya

This project undertaken by PhD student Gregg Pyke at Heriot Watt (now at Oxy) was supervised, Dr Andy Gardiner, Prof Patrick Corbett, and also Prof Jonathan Redfern, and examined the Controls on Reservoir Quality within the Cambro-Ordovician Sandstones of the Saharan Platform. Extensive fieldwork was undertaken in the Murzuk Basin, integrated with a large subsurface dataset, built into a regional Petrel model. Diagenesis of the Memouniat reservoir has been modeled using the Touchstone software™

Publications:

No publications have been forthcoming from this work. A number of ppt presentations and extended abstracts are available on the NARG secure server.

PhD Thesis:

This work has still to be submitted for a PhD. A number of ppt presentations and preliminary reports are available to the sponsors.

14.9 Source Rock Hunter Project and Basin Modelling

Early work on regional source rocks was undertaken by postdoctoral researcher Dr Sebastian Luning, supported by Stefan Lubeseder and Dr Jonathan Redfern. This work aimed to assess the source rock quality of Palaeozoic shales from outcrop studies, that had proved difficult to quantify due to intense weathering. The project included the analysis of a number of methods to allow more accurate regional mapping of source rock facies including surface exposures. Based on their characteristic uranium gamma-radiation and pyrite framboid distribution, the original organic richness of the Silurian / Upper Devonian shales in weathered outcrops was mapped in Libya. A model for the distribution of the rich source rocks was developed. Fieldwork was carried in the Moroccan Anti-Atlas where the Frasnian and Silurian hot shales were studied at outcrop using a portable gamma-ray spectrometer. The unit is typically marked by enrichment in uranium. Additional fieldwork was carried out on the Silurian Tannezuft Shales outcrops documented in Ghat (SW Libya) and Algeria for the Silurian and Devonian source facies.

The project was continued by Dr Alvaro Jimenez-Berracosso (now with Repsol). New field investigations were carried out in north central Tunisia, examining the organic-rich sediments of the Bou Dabbous Fm (lower Eocene). The research addressed the controls on the development of the organic richness and assess its distribution stratigraphically and aerially, in order to improve source rock quality predictions.

Other research (including proprietary consulting projects) has focused on the Silurian (Tanezuft Shales) in Libya and Morocco, Cenomanian /Turonian and Toarcian source rocks.

Future work will initially focus on the Cenomanian / Turonian in Morocco, with Prof Kevin Taylor from the University of Manchester. These outcrops, integrated with available offshore well and seismic data, will provide an analogue for offshore source intervals along the Atlantic margin. Development of the online database is continuing for all the main source horizons and potentially significant intervals.

NARG has also been working on basin modelling projects, integrated to petroleum system analysis, since its inception. We have access to the latest basin modelling software, and through collaborations, can undertake heat flow and subsidence history analysis (FT, Vr etc). The capability is enhanced now through the membership of TU Delft.

Publications:

Burwood R., Redfern J., and Cope M. (2003) Geochemical evaluation of East Sirte Basin (Libya) petroleum systems and oil provenance. In *Petroleum Geology of Africa: New Themes and Developing Technologies*, Vol. 207 (ed. T. J. Arthur, D. S. MacGregor, and N. R. Cameron), pp. 203-204. Geological Society of London Special Publication.

Lüning, S., Craig, J., Loydell, D. K., Storch, P. & Fitches, W. R. (2000): Lowermost Silurian 'hot shales' in North Africa and Arabia: Regional Distribution and depositional model. *Earth Science Reviews* 49: 121-200.

Lüning, S., Adamson, K., Craig, J. (2003a): Frasnian 'Hot Shales' in North Africa: Regional Distribution and Depositional Model. In: Arthur, T. J., Macgregor, D. S., Cameron, N. (Eds.), *Petroleum Geology of Africa: New Themes and developing technologies*, Geol. Soc. (London) Sp. Publ. 207: 165-184.

Lüning, S., S. Kolonic, D. Loydell, J. Craig (2003b): Reconstruction of the original organic richness in weathered Silurian shale outcrops (Murzuq and Kufra basins, southern Libya). *GeoArabia* 8: 299-308.

Lüning, S., S. Kolonic, E. M. Belhadj, Z. Belhadj, L. Cota, G. Baric, T. Wagner (2004): Integrated depositional model for the Cenomanian-Turonian organic-rich strata in North Africa. *Earth-Science Reviews* 64: 51-117.

Underdown, R., and Redfern, J., (2007), The importance of constraining regional exhumation in basin modelling: a hydrocarbon maturation history of the Ghadames Basin, North Africa., *Petroleum Geoscience*, V 13, p 1-19

Underdown, R., and Redfern J., (2007), Constraining the burial history of the Ghadames Basin, North Africa: An integrated analysis using sonic velocities, vitrinite reflectance data and apatite fission track ages. *Basin Research*, Volume 19, Number 4, pp. 557-578 (22)

Underdown, R., and Redfern, J., (2008), Petroleum Generation and Migration in the Ghadames Basin, North Africa: A 2D Basin Modelling Study, *AAPG Bulletin*, V. 92, No. 1, pp. 53-76.

Bodin S., E. Mattioli, S. Frohlich, J.D. Marshall, L. Boutib, S. Lahsini, J.Redfern (2010). "*Toarcian carbon isotope shifts and nutrient changes from the Northern margin of Gondwana (High Atlas, Morocco, Jurassic): Palaeoenvironmental implications.*" *Palaeogeography, Palaeoclimatology, Palaeoecology*, 297, pp 377-390.

Reports:

Additional reports are available of the Jurassic source rocks of Fuerteventura, and regional source rock analysis of the Silurian in Morocco and Libya.

PhD Thesis:

2006: Dr Ruth Underdown (now a school teacher): Assessing the impact of regional unconformities on the maturation and migration of hydrocarbons within the Ghadames Basin, North Africa. NARG Funded

14.10 Carbonate Reservoir Studies: Dolomitisation of Late Cretaceous Reservoirs, North Africa

The influence of dolomitisation on Late Cretaceous carbonates in North Africa is often critical to reservoir development. The study has analysed the superbly exposed section along the Jeffara escarpment of southern Tunisia, together with analogue outcrops in Northern Spain. These outcrops provide an excellent opportunity to study the extensively dolomitised Upper Albian-Lower Turonian shallow water carbonates of the Zebbag Formation (Rhadouane, Kerker and Gattar Members), and similar facies in Spain, which are potential outcrop analogues for reservoirs currently under production and appraisal in North Africa. This study comprised a multi-disciplinary, multi-scale approach using field, petrographical and geochemical data to better constrain the depositional history, diagenetic history and source of diagenetic fluids.

Publications:

3 papers in preparation

PhD Thesis: Richard Newport (2014)

14.11 FRAC -Fractured Reservoir Analogues Carbonates.

This project was led by postdoctoral fellow Dr Guy Spence. Outcrop analogues of subsurface naturally fractured carbonate hydrocarbon reservoirs in Egypt were studied to improve our understanding of fracture development and prediction in these complex reservoirs. Field studies were undertaken in Egypt prior to the political situation changing. The project involved the use of DGM /LiDAR 3-D field mapping of fractured carbonate outcrops, sedimentary logging, sampling and mapping. Data processing and analysis used the Manchester in-house software VRGS and Schlumberger's Petrel software. The aim was to improve understanding of fracture characterisation and property modeling.

Publications:

Spence, G.H., Redfern, J., Aguilera R., Bevan, T., Cosgrove, J.W., Couples, G., Daniel, J-M. (eds) (2014), *Advances in the Study of Fractured Reservoirs*. Geological Society, London, Special Publication v. 374. and papers therein

14.12 Diagenesis and thermal history of the Illizi Basin during the Ordovician, Algeria

Kara English was funded by Petroceltic (provided data and funding) and also supported by NARG.

This study focused on the southern Illizi basin in Algeria, where a substantial new dataset has been acquired by Petroceltic International as part of the recent appraisal of the Ain Tsila gas-condensate discovery. A number of complementary methods are being used to constrain the thermal and burial history of the Ordovician reservoirs in the Ain Tsila field. The techniques include: estimates of missing stratigraphy based on regional observations and cross-sections, estimates of the magnitude of exhumation based on sonic velocity 'over-compaction' of regionally homogeneous shale and sandstone packages, estimates of peak burial temperature and paleo-geothermal gradients based on vitrinite reflectance data, and constraints on thermal history provided by apatite fission track (AFT) data. The resulting burial history models combine all available fluid inclusion and source rock data to generate a model of the timing of hydrocarbon generation and migration from the primary source rocks within the basin. These models are being used to predict the timing of a potential early-oil fill within the Ordovician reservoirs in the Ain Tsila field, and also the timing of the main gas- condensate charge. These burial history models were utilized in order to construct some conceptual sandstone diagenesis models using Touchstone software, and to make predictions regarding the (spatial and vertical) variation of reservoir quality across the Ain Tsila field.

Publications:

English K.L., Redfern, J., Corcoran, D.V., English, J.M., Yahia R.C. 2016. Constraining burial history and petroleum charge in exhumed basins: New insights from the Illizi Basin, Algeria. AAPG Bulletin. DOI: 10.1306/12171515067

English, K., Redfern, J., Bertotti, G., English, J., Cherif, R.Y. 2016. Intraplate uplift: new constraints on the Hoggar dome from the Illizi basin (Algeria). *Basin Research* . doi: 10.1111/bre.12182

English, J., English, K., Corcoran, D.V., Fabrice Toussaint F., 2016, Exhumation charge: The last gasp of a petroleum source rock and implications for unconventional shah resources, *AAPG Bulletin* 100(1):p 1-16

PhD Thesis: Kara English February 2017

14.13 Characterisation of Cretaceous Depositional Systems along the Atlantic Passive Margin, Morocco – A source to sink study

An interdisciplinary and multi-scale research project to characterize and evaluate the evolution of the Cretaceous depositional systems Onshore Morocco along the Atlantic Seaboard, extending offshore along the Morocco passive margin. To improve understanding of the depositional systems, facies modeling and basin evolution, with the implications for petroleum systems and modeling reservoirs, source distribution, generation and migration, and seal. The research will undertake detailed analysis of onshore outcrops to develop improved sedimentological models and establish depositional facies distributions through time, provenance, diagenesis and improved chronostratigraphy.

This project commenced in January 2014, and results have been delivered to the sponsors. The project integrated analysis of available offshore subsurface data provided by ONHYM, including an offshore 2D seismic grid and access to well data and reports. NARG has an MOU with ONHYM to cooperate on this study, building on the very strong links over the last 20 years. Additional data was provided by sponsoring companies (Kosmos 3D), to assist in mapping the offshore in order to constrain the source to sink models, and assess the evolution of the Cretaceous system and controls on sedimentation (salt tectonics) and basin evolution.

Research team comprised 4 PhDs (Tim Luber , Angel Arantegui, Leonardo Muniz Pichel (Brazilian Gov Scholarship) based in Manchester , Remi Charton (based in TuDelft) . All have now graduated and their theses are available. Academic staff supervision from Prof Jonathan Redfern, Prof Giovanni Bertotti and Prof Joep Storms from Manchester, TU Delft and Amsterdam (VUA), and Dr Luc Bulot (Manchester). Further work is ongoing, with a 2 new PhDs which commenced in 2017 /2018 to extend the work stratigraphically and also undertake a regional provenance study.

Publications:

Luber, T.L., Bulot, L.G., Redfern, J., Frau, C., Arantegui, A. and Masrour, M. (2017) A revised ammonoid biostratigraphy for the Aptian of NW Africa: Essaouira-Agadir Basin, Morocco. *Cretaceous Research*, 79, p.12-34.

Luber et al., 2018, A revised chronostratigraphic framework for the Aptian of the Essaouira-Agadir Basin, a candidate type section for the NW African Atlantic Margin, *Cretaceous Research*.

Charton et al., 2018; The Sidi Ifni transect across the rifted margin of Morocco - *Journal of African Earth Sciences*

Muniz Pichel, L., Finch, E., Huuse, M. & Redfern, J. (2017), The influence of shortening and sedimentation on rejuvenation of salt diapirs: A new Discrete-Element Modelling approach, *Journal of Structural Geology*. DOI: 10.1016/j.jsg.2017.09.016

Muniz- Pichel et al., 2019, The influence of base-salt relief, rift topography and regional events on salt tectonics offshore Morocco;, *Marine and Petroleum Geology*, DOI: <https://doi.org/10.1016/j.marpetgeo.2019.02.007>

PhD Theses:

3 theses have been completed, Luber, Arantegui, Muniz-Pichel

14.14 Jurassic Carbonate reservoir architecture, evolution and characterisation: Atlantic Margin

The study focused on stratigraphic architecture, paleogeography and facies trends of Jurassic carbonates along the Moroccan Atlantic Margin, as well as age relationships in the basin. This study involved extensive outcrop work, new biostratigraphic dating and sample analysis. This comprises the largest dataset collected on the Jurassic carbonates and provides a comprehensive re-analysis of the entire sequence. Results were integrated with subsurface datasets. The study has impact on active oil and gas exploration, in the light of hydrocarbon discoveries in Jurassic carbonates both in Morocco and in the conjugate basins of Canada.

PhD: Aude Duval Arnould, working on the large-scale architecture, stratigraphy and facies evolution. Supervisors: Dr Stefan Schroder and Prof Jonathan Redfern. The work is continuing with a linked diagenetic (dolomitisation) PhD and further post doctoral studies.

PhD Theses: Currently awaiting viva.

14.15 Source Rock Hunter: Controls on distribution and quality of the Turonian / Cenomanian Source rocks along the Atlantic Margin

This project aimed is to characterise the Cenomanian / Turonian source rocks outcropping onshore Morocco and correlate with the offshore penetrations. Geochemical data was collated and new data produced from examination of outcrop and cuttings data from both the Atlantic margin (Tarfaya and Agadir) and Tethyan margin (Errachidia). The study addressed the controls and processes of source rock development and enrichment. This has implications north in the offshore Rabat area and in the Rhif, where the Cen-Tur is an active source, and extending south along the Atlantic margin. This is a contribution to the NARG Source Rock Hunter project.



PhD student: Jianpeng Wang (Chinese Gov. Scholarship / NARG) was supervised by Prof Kevin Taylor and Prof Jonathan Redfern.

PhD Theses: Jianpeng Wang – currently making corrections before final award

Associated (Non NARG Funded) Projects

14.16 Controls on carbonate reservoir development, Kotla Graben, Sirt Basin, Libya.

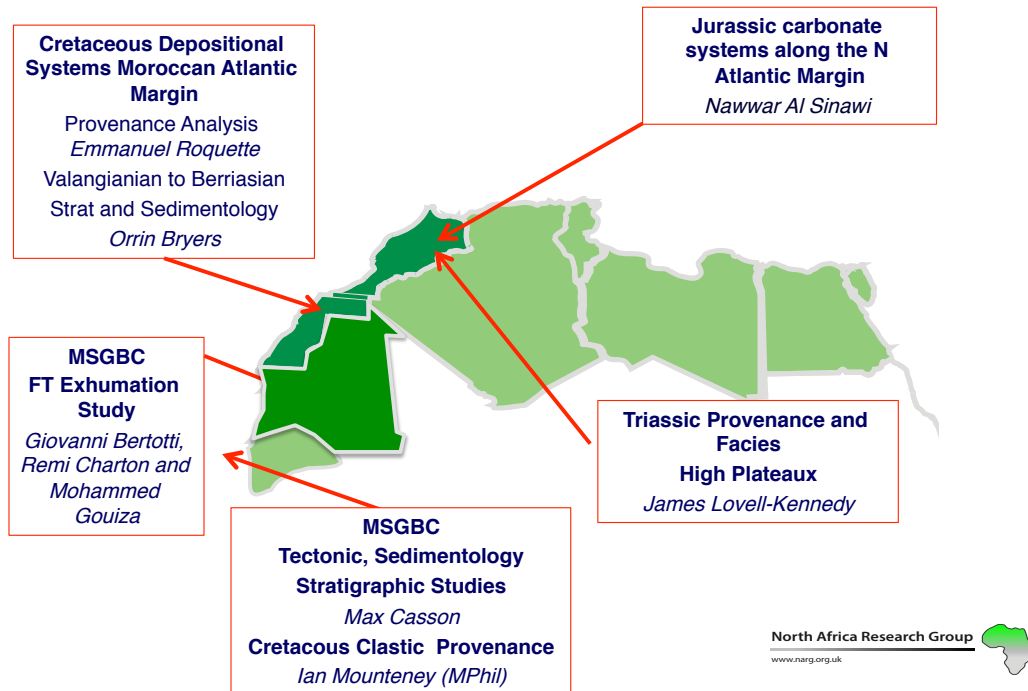
The evolution of the Western Sirt Basin in the region of the Dahra Platform, Amin High and Kotla Graben was being evaluated by integrating 2D /3D seismic and data from 36 wells. Three tectonic styles were identified involving regional Pre-rift intra-continental sag, complex multi-stage rifting and modification by wrenching. A major horst-graben system configuration was delineated, which allowed mapping of fault distribution and timing throughout the area. Time, interval velocity, isochron, depth, isopach and lithofacies contour maps of the selected (12) horizons have been constructed. These maps were used to interpret the subsurface architecture of the area from thickness, depth variations and velocity anomalies, in terms of tectonic effect and its control on thickness and facies distribution throughout the Dahra Platform and Kotla Graben area.

PhD student: Mohammed Salem was funded by the Libyan Government, with data supplied by AGOCO:

PhD thesis: Mohammed Salem (restricted)

15. Current Research Projects:

Ongoing Studies



15.1 Characterisation of Cretaceous Depositional Systems along the Atlantic Passive Margin, Morocco – A source to sink study- PHASE II

An interdisciplinary and multi-scale research project to characterize and evaluate the evolution of the Cretaceous depositional systems Onshore Morocco along the Atlantic Seaboard, extending offshore along the Morocco passive margin. Phase II aims to extend the work down into the Valangianian, Berriasian and Hauterivian, to improve understanding of the depositional systems, facies modeling and basin evolution, with the implications for petroleum systems and modeling reservoirs, source distribution, generation and migration, and seal. The research will undertake detailed analysis of onshore outcrops to develop improved sedimentological models and establish depositional facies distributions through time, provenance, diagenesis and improved chronostratigraphy.

This is being carried out in tandem with project 15.2. Research team comprises PhD Orrin Bryers. Academic staff supervision from Prof Jonathan Redfern and Dr Luc Bulot.

15.2 Provenance study of the Jurassic to Early Cretaceous depositional systems, Agadir and Tarfaya Basin, Morocco.

This project commenced in September 2016. It is applying an array of techniques, including heavy mineral analyses, zircon provenance and FT dating, and feldspar to assess the possible provenance locations and contribution history for the Jurassic to Early Cretaceous depositional systems, linking existing work being undertaken on the sedimentology on the margin and the thermal geochronology study undertaken at Tu Delft. It is being conducted in collaboration with UCD / Galway University, Eire.

PhD: Emmanuel Roquette, 1st year, supervised by Dr Stefan Schroeder, Prof Jonathan Redfern and Prof Giovanni Bertotti, and Dr Shane Tyrrell at University College Galway.

15.3 Jurassic Carbonate reservoir architecture, evolution and characterisation: Atlantic Margin:

The postdoctoral study builds on the completed PhD and is further developing the paleogeography and facies trends of Jurassic carbonates and interbedded clastics along the Moroccan Atlantic Margin, as well as age relationships in the basin. Part of the work will be outcrop-based. Results will be integrated with subsurface datasets, seismic and well data. The study will have impact on active oil and gas exploration, in the light of hydrocarbon discoveries in Jurassic carbonates both in Morocco and in the conjugate basins of Canada. Reconnaissance studies of the Jurassic Outcrops north of Agadir have already been conducted.



PostDoc: Aude Duval Arnould (Working on the large-scale architecture, stratigraphy and facies evolution. Supervisors: Dr Stefan Schroeder and Prof Jonathan Redfern.

15.4 Characterising the dolomitisation history and reservoir quality of Jurassic carbonates along the Atlantic Margin of Morocco and Nova Scotia

This project commenced in September 2016, with a student on a Scholarship from PDO. The project integrates with the existing study of the Jurassic carbonates, examining the distribution and controls on dolomitisation of the Jurassic carbonates. It has involved extensive fieldwork and sample analysis using a suite of geochemical techniques. (Petrography, cathode-luminescence, isotope analysis, Qemscan /SEM etc).

PhD: Nawar Al-Sinawi (PDO/NARG Sponsored – final year) Working on the control on dolomitisation and reservoir characterization. Supervisors: Dr Cathy Hollis, Dr Stefan Schroeder, Prof Jonathan Redfern.

15.5 Tectono-stratigraphic Evolution of the MSGBC Basin and wider West African and Conjugate margin

Recent world-class discoveries in the Mauritania-Senegal-Guinea Bissau-Conarky (MSGBC) Basin by oil companies sponsoring the North Africa Research Group (NARG) have attracted the attention of our current research. Mesozoic stratigraphy in the MSGBC Basin records the post-rift evolution of the North West African Atlantic passive margin following late Triassic rifting. These strata constitute to numerous new hydrocarbon plays that oil companies are chasing in the whole Central Atlantic region.

The project aims to progress the understanding of the Mesozoic tectono-stratigraphic evolution of the MSGBC Basin and wider Central Atlantic region using a multi-disciplinary, integrated approach to basin analysis. The study has been split into two distinct phases; the first will aim to create a new integrated stratigraphic framework for the Central Atlantic region by collecting new core samples from IODP cores, outcrop data from Maio – Cape Verde and Cap de Naze – Senegal, and exploration well data from onshore Senegal and offshore Suriname. Following this, the stratigraphic framework will be applied to regional seismic data in the MSGBC Basin to understand the spatially and temporal controls on depositional systems. At Tu Delft, Giovanni Bertotti is leading the linked thermochronology study, aiming to quantify uplift in the source area using low-T geochronology tools. An MPhil student, Ian Mounteney is working the linked regional provenance study.

PhD student: Max Casson is working on the 'sink' part of this project with supervision from Jonathan Redfern, Luc Bulot, Jason Jeremiah and Mads Huuse.

Publications:

Casson, M., Cavin, L., Jeremiah, J., Bulot, L.G. and Redfern, J. (2018) Fishing in the Central Atlantic, an earliest Cenomanian ichthyodectiform from DSDP Site 367, Cape Verde Basin. *Journal of Vertebrate Paleontology*, p.1-5.

15.6 Provenance and reservoir characterisation of Triassic continental clastics across Eastern Morocco

Results from the recent Tendirra wells drilled in Eastern Morocco prove economic flowrates from Late Triassic continental sandstones. Sourced from the Palaeozoic and trapped with post Hercynian rift structures, the play has many similarities to the prolific TAGI play in the Berkine Basin and offers potential for extension of the petroleum system further west into Morocco.

Reservoir quality and thickness is a key uncertainty and to better understand this, studies are ongoing to assess the main controls on the depositional systems and provenance. Augmented by data from oil exploration wells, the research is investigating how the basin fill changes both temporally and spatially. This study compares the provenance and character of the Triassic section outcropping in Oukaimeden Basin (F4, F5 and F6 sandstones) with the age equivalent units in the Kerrouchen Basin, Middle Atlas, and east to outcrops in the Oujda Mountains in the Eastern Meseta and to the subsurface, accessing data from vintage exploration wells and core data from the recent Tendirra discovery.

A heavy mineral study is being undertaken in order to constrain the provenance of these sediments. Palaeocurrents data and published provenance studies suggest a drainage divide within the Massif Ancien, separating the Atlantic real to the west from the eastern Tethyan domain. Key questions include whether a long distance axial system existed, running sub parallel to the main structural trend, transported clastics from the Central High Atlas east-northeast to Tethys or if a more south to north feeder systems prevailed. The results also aim to address the role of intra-basinal topography through time: how this affected the distribution of fluvial systems and the role of local sediment source from basement blocks. Finally the work will attempt to integrate the regional data to evaluate evolution of the basins as they mature, associated with rift linkage.

PhD Student: James Lovell-Kennedy, supervised by Prof Jonathan Redfern.

15.7 Post-Variscan vertical movements in Mauritanian / Senegal: Implications for dynamic topography on the margin of the Atlantic to Mesozoic source-to-sink systems

Regional sampling to extend the Morocco LowT geochronology south through the Mauritania and Senegal Mauritanides. The samples collected during the first field campaign of February 2017 have been successfully processed and apatites measured for Apatite Fission Tracks and U, Th He. Further sampling was undertaken in 2018 in Senegal, and those samples are now being processed. This is the first consistent set of exhumation ages from the Mauritanides of Mauritania. Continuing the “anomalous” pattern documented in Morocco the measurements confirm our working hypothesis that large portions of the passive continental margin of NW Africa experienced exhumation during post-rift, and that, therefore, could have been the source for the terrigenous sediments targeted by hydrocarbon exploration in the Mauritania offshore.

Researchers: Prof Giovanni Bertotti, Dr Mohamed Gouiza (Leeds), Dr Remi Charton.

Publications:

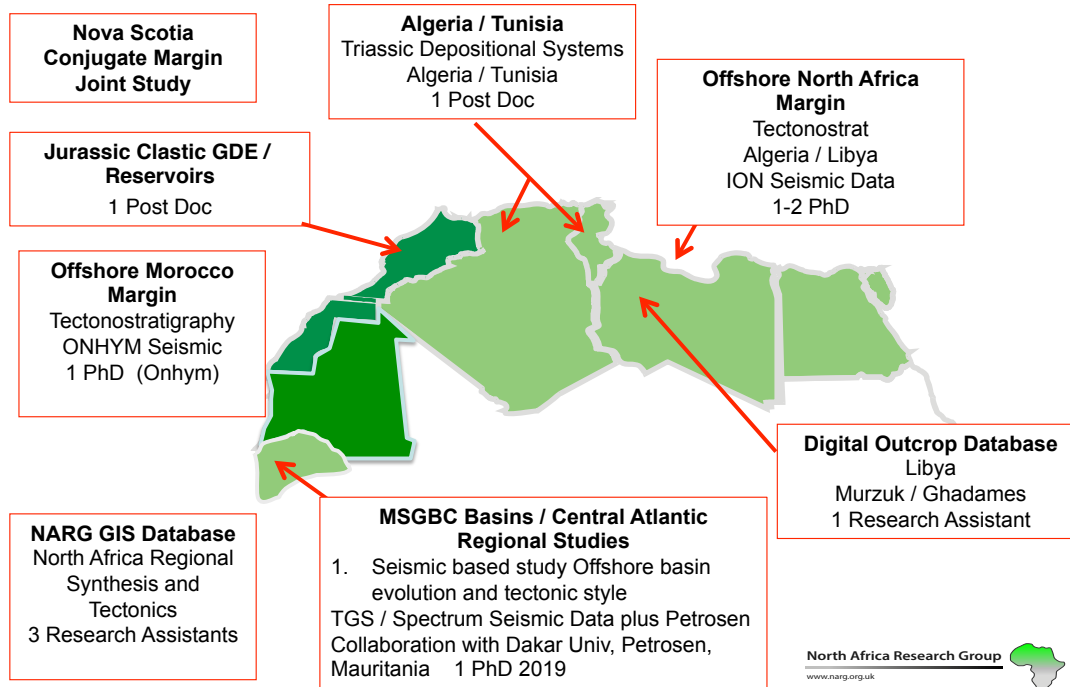
Gouiza, M., Charton, R, Bertotto G, Andriessen P and Storms J.E.A (2015) Post-Variscan evolution of the Anti-Atlas belt of Morocco constrained from low-temperature geochronology. *Int J Earth Sci (Geol Rundsch)*

Charton, R., Bertotti, G., Arantegui, A. and Bulot, L. (2018) The Sidi Ifni transect across the rifted margin of Morocco (Central Atlantic): Vertical movements constrained by low-temperature thermochronology. *Journal of African Earth Sciences*, 141, p.22-32.

16. New Projects commencing in 2019

It is anticipated the 2 to 4 additional PhDs will commence in 2019. Projects for consideration:

Planned Future Studies



Further details available on all these projects on the NARG Webpages: www.narg.org.uk.

17. List of Researchers:

Staff:

Manchester
Prof Jonathan Redfern
Dr David Hodgetts
Dr Cathy Hollis
Dr Stefan Schroeder
Dr Mads Huuse
Prof Kevin Taylor
Dr Luc Bulot

Heriot Watt
Prof Dorrik Trow
Dr Andrew Gardiner

TU Delft
Prof Giovanni Bertotti
Prof Joep Storms
Prof Allard Martinus
Dr Remi Charton
(PostDoc)

Galway University
Dr Shane Tyrell

Aix-Marseille University
Dr Luc Bulot

Aarhus University
Dr Stefan Bodin

GIS Administrator:
Kofi Owusu

Research Assistants:
Tim Ohiara
Calum Knowles
Ginny-Marie Bradeley

Current PhDs:

Aude Duval-Arnould (Manchester)
Jianpeng Wang (Chinese Gov. Scholarship)
Nawwar Al-Sinawi (PDO / Manchester)
Emmanuel Roquette (Manchester)
Orrin Bryers (Manchester)
James Lovell Kennedy (Manchester)

MPhil:

Ian Mounteney (Manchester / BGS)

Completed PhDs (University / Currently with):

Dr Ruth Underdown (Manchester / Teacher)
Dr Stefan Lubeseder (Manchester/ Wintershall)
Dr Nadine Mader (Manchester / Consultant)
Dr Ivan Fabuel Perez (Manchester / Exxon)
Dr Vicky Catterall (Manchester / Exxon)
Dr Mustafa Karer (Manchester/ Consultant)
Dr Xavier Van Lanen (Manchester / Equinor)
Dr Jonathan Wood (Manchester / Shell)
Dr Laurent Petitpierre (Manchester / Equinor)
Dr Myron Thomas (Manchester / Shell)
Dr Richard Newport (Manchester / Shell)
Dr Kara English (Manchester / PDP Eire)
Dr Tim Luber (Manchester / Equinor)
Dr Angel Arantegui (Manchester/ Consultant)
Dr Remi Charton (PostDoc TuDelft)
Dr Mohamed Salem (Libyan Gov. Sponsors)
Dr Leonardo Muniz-Pichel (Brazilian Gov
Scholarship)/ PostDoc Imperial)

MRes:

Habid Awatif (MRes) Onhym

Pending PhDs:

Gregg Pyke (Heriot Watt / Oxy)

Previous PostDocs (currently with)

Dr Ian Carr (Worthing College)
Dr Sebastian Luning (Galp Energia)
Dr Gianluca Badalini (BG)
Dr Dorthie Hansen (Statoil)
Dr Stefan Lubeseder (Wintershall)
Dr Sebastian Frohlich (Statoil)
Dr Stephan Bodin (Aarhus Univ)
Dr Alvaro Jimenez (Repsol)
Dr Catherine Baudon (maternity Leave)
Dr Guy Spence (Consultant)



18. Selected Publications:

1. Burwood R., Redfern J., and Cope M. (2003) Geochemical evaluation of East Sirte Basin (Libya) petroleum systems and oil provenance. In *Petroleum Geology of Africa: New Themes and Developing Technologies*, Vol. 207 (ed. T. J. Arthur, D. S. MacGregor, and N. R. Cameron), pp. 203-204. Geological Society of London Special Publication.
2. Badalini G., Redfern J., and Carr I. D. (2002) A synthesis of current understanding of the structural evolution of North Africa. *Journal of Petroleum Geology* 25(3), 249-258.
3. Fello, N., Lüning, S., Štorch, P., and Redfern, J. (2006), Identification of early Llandovery (Silurian) anoxic palaeo-depressions at the western margin of the Murzuq Basin (southwest Libya), based on gamma-ray spectrometry in surface exposures. *GeoArabia* 11 (3): 101-118.
4. Redfern, J., Hodgetts, D. & Fabuel-Perez, I. (2007). Digital analysis brings renaissance for petroleum geology outcrop studies in North Africa. In: *First Break*, 25, 81-87.
5. Underdown, R., and Redfern, J., (2007), The importance of constraining regional exhumation in basin modelling: a hydrocarbon maturation history of the Ghadames Basin, North Africa., *Petroleum Geoscience*, V 13, 1-19
6. Underdown, R., and Redfern J., (2007), Constraining the burial history of the Ghadames Basin, North Africa: An integrated analysis using sonic velocities, vitrinite reflectance data and apatite fission track ages. *Basin Research*, Volume 19, Number 4, 557-578(22)
7. Underdown, R., and Redfern, J., (2008), Petroleum Generation and Migration in the Ghadames Basin, North Africa: A 2D Basin Modelling Study, *AAPG Bulletin*, V. 92, No. 1, 53-76.
8. Hansen, D.H., Redfern, J., Federici, F., di Biase, D. and Bertozzi, G., (2008), Miocene igneous activity in the northern subbasin, offshore Senegal, NW Africa, *Marine and Petroleum Geology*, Volume 25, Issue 1, 1-15

9. Fabuel-Perez, I., Hodgetts, D., & Redfern, J., (2009), A new approach for outcrop characterization and geostatistical analysis of a low-sinuosity fluvial-dominated succession using digital outcrop models; Upper Triassic Oukaimeden Sandstone Formation, central High Atlas, Morocco *AAPG Bulletin*, 93, 6, pp. 795-827
10. Lubeseder, S., Redfern, J., Boutib, L., (2009), Mixed siliciclastic-carbonate shelf sedimentation- Lower Devonian sequences of the SW Anti-Atlas, Morocco Source: *Sedimentary Geology*, 215, 1-4, pp. 13-32
11. Fabuel-Perez, I.; Redfern, J.; Hodgetts, D., (2009), Sedimentology of an intra-montane rift- controlled fluvial dominated succession: The Upper Triassic Oukaimeden Sandstone Formation, Central High Atlas, Morocco, *Sedimentary Geology*, v. 218, iss. 1-4, pp. 103-140.
12. Baudon, C., Fabuel-Perez, I. and Redfern, J. (2009). "Structural style and evolution of a Late Triassic rift basin in the central High Atlas, Morocco; controls on sediment deposition." *Geological Journal*, 44(6): pp. 677-691.
13. Van Lanen, X.M.T., Hodgetts, D., Redfern, J., Fabuel-Perez, I. (2009). " *Applications of digital outcrop models; two fluvial case studies from the Triassic Wolfville Fm., Canada and Oukaimeden Sandstone Fm., Morocco.*" *Geological Journal*, 44(6): 742-760.
14. Fröhlich S., J. Redfern, L. Petitpierre, J. Marshall, M. Power, P. Grech (2009), Diagenesis and reservoir quality evolution of Lower Carboniferous fluvial channels, western Libya) . *Journal of Petroleum Geology*
15. Bodin S., E. Mattioli, S. Fröhlich, J.D. Marshall, L. Boutib, S. Lahsini, R.Redfern (2010). "*Toarcian carbon isotope shifts and nutrient changes from the Northern margin of Gondwana (High Atlas, Morocco, Jurassic): Palaeoenvironmental implications.*" *Palaeogeography, Palaeoclimatology, Palaeoecology*, 297, pp 377-390.
16. Bodin, S., Wood, J., Petitpierre, L., Redfern, J. (2010). "*Timing of Early to Mid-Cretaceous tectonic phases along North Africa: New insights from the Jeffara escarpment (Libya-Tunisia).*" *Journal of African Earth Sciences* 58, 3. pp 489-506.
17. Thomas, M. F. H., Bodin, S., Redfern, J., Irving, D. H. B. (2010). "*A constrained African craton source for the Cenozoic Numidian Flysch: Implications for the palaeogeography of the western Mediterranean basin.*" *Earth Science Reviews* 101, 1. pp 1-23.
18. Fröhlich, S., Petitpierre, L., Redfern, J., Grech, P., Bodin, S., Lang, S. (2010). "*Sedimentological and sequence stratigraphic analysis of Carboniferous deposits in western Libya: recording the sedimentary response of the northern Gondwana margin to climate and sealevel changes.*" *Journal of African Earth Sciences* 57 (4), pp. 279-296
19. Catterall, V., Redfern, J., Gawthorpe, R.L., Hansen, D.M & Thomas, M.H.F (2010), Architectural Style and Quantification of a Submarine Channel-Levee Systems located in a structurally complex area: Offshore Nile Delta, *Journal of Sedimentary Research*, v. 80; no. 11; pp. 991-1017; DOI: 10.2110/jsr.2010.084
20. Fabuel-Perez, I., Hodgetts, D. and Redfern, J. (2010). "*Integration of digital outcrop models (DOMs) and high resolution sedimentology; workflow and implications for geological modelling; Oukaimeden Sandstone Formation, High Atlas (Morocco).*" *Petroleum Geoscience*, 16, 133- 154.133-154.
21. Lubeseder S., J. Redfern, L. Petitpierre, S. Fröhlich. (2011). Stratigraphic trapping potential in the Carboniferous of North Africa: developing new play concepts based on integrated outcrop sedimentology and regional sequence stratigraphy (Morocco, Algeria, Libya). *Geological Society, London, Petroleum Geology Conference series 2011*, v. 7, p. 725-734, doi: 10.1144/0070725
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19. Contact Details:

Prof Jonathan Redfern, Director of Research

Tel: +44 (0)161 275 3773

Email: jonathan.redfern@manchester.ac.uk

School of Earth and Environmental Sciences, The University of Manchester
Williamson Building, Oxford Road, Manchester, UK, M13 9PL





Atlantic Margin Petroleum Systems Workshop / Fieldtrip

May 4th – 11th
2019

Summary: 7-day field workshop in Morocco, examining the entire Central Atlantic Margin sequence from Paleozoic basement, Triassic continental rift sequences to Jurassic passive margin carbonates and Early Cretaceous paralic deposits, the feeder systems to potential offshore deepwater reservoirs. Regional tectonics and salt evolution.

Aim: Evaluate the tectono-stratigraphic framework, reservoir characterization, source to sink and depositional systems. Triassic, Jurassic and Cretaceous petroleum systems. Analogue to plays offshore Morocco, Mauritania, Senegal, The Gambia and the Nova Scotia / US conjugate margin.

Teaching Methods: 1-day workshop followed by a 6-day fieldtrip. Integration of outcrop observations with subsurface data.

Accommodation: Accommodation in quality 3-5 star hotels.

Transport: Modern air-conditioned Mercedes Sprinter 16-seater coaches, with seat belts and experienced local drivers. Airport transfers.

Safety: The field trip is led by Prof Jonathan Redfern and academic staff /researchers from NARG, who have been undertaking research in Morocco for more than 15 years. Full HSE compliance, with emergency response procedures. All outcrops have been visited and assessed for safety. Hard hats, high-vis vests provided, full medical kits on board coaches. Details of local hospitals provided. Local authorities informed of our planned routes. Daily HSE briefings and reporting.

Who should attend: Suitable for both new hires and experienced geologists /engineers.

Triassic High Atlas



Previous Course Attendees :

*Kosmos, Repsol, ChevronTexaco,
Equinor, Cairn Energy, Woodside,
Sound Energy, Genel*

Jurassic transect en-route
to Immouzer



Early Cretaceous shelfal sediments - Assaka



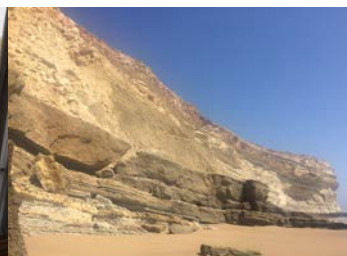
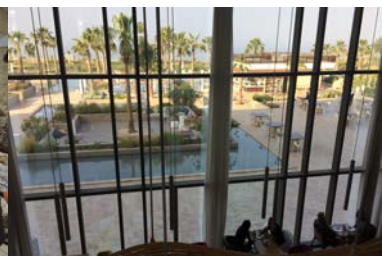
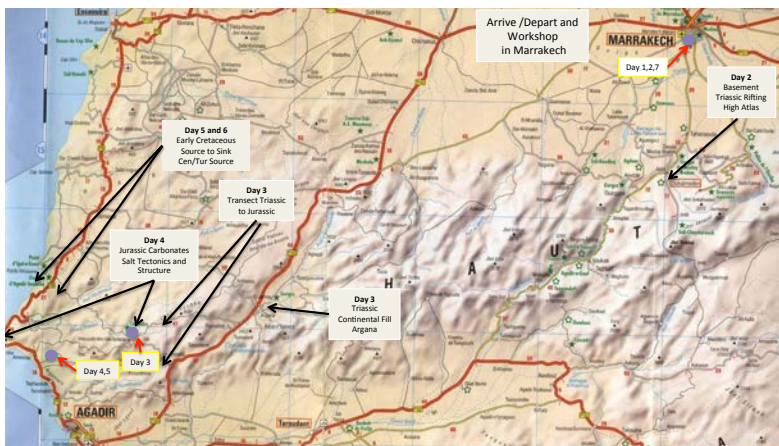
Itinerary:

Date	Agenda	Accommodation
Sat May 4th	Arrival Marrakech	Marrakech
Sun May 5th	Marrakech: Workshop / HSE	Marrakech
Mon May 6th	Oukamaiden Triassic Rift – Continental clastic fill, High Atlas	Marrakech
Tue May 7th	Argana Valley Triassic syn-rift red beds clastics . Transect to Jurassic passive margin carbonates	Immouzer
Wed May 8th	Immouzer Jurassic Carbonate Facies Salt Dynamics/Tectonics	Taghazout
Thurs May 9th	Cap Ghir ,Jurassic Reefal facies Architecture and reservoir development Azzazol Cen/Turonian Source Rock	Taghazout
Fri May 10th	Tamri/ Tiskatine,/Assaka , Early Cretaceous Paralic Deposits (N Agadir)	Taghazout
Sat May 11th	N Agadir , Early Cretaceous Return to Marrakech (arrive 4.30pm) <i>(option to stay extra night in Marrakech at own cost)</i>	Depart Morocco late pm

Cost:

Price is £3200 per person plus VAT, payable in advance

Price is inclusive of field guide, airport transfer, single room accommodation, all meals and local transport. Price excludes flights to and from Marrakech, drinks and other incidentals





Eastern Morocco Palaeozoic Petroleum Systems Field course

10th to 17th Nov
2019

Summary: 7-day field workshop examining the Palaeozoic and Triassic depositional sequence exposed in Eastern Morocco. From basement, Ordovician glaciogenic facies, Silurian carbonates and black shales, Devonian mixed carbonate/clastics and the famous mud mounds, culminating with the overlying Triassic red beds in the Kerrouchen Basin.

Aim: Evaluate the tectono-stratigraphic framework, reservoir characterization, source rocks and depositional systems. Analogue to plays to Algeria, Libya and Tunisia and the opening petroleum systems in the High Plateaux., Boudenib Basin, Eastern Morocco

Teaching Methods: 7-day fieldtrip. Integration of outcrop observations with subsurface data, evening presentation to reinforce observations.

Accommodation: Accommodation in quality 3-5 star hotels.

Transport: Modern air-conditioned Mercedes Sprinter 16-seater coaches, with seat belts and experienced local drivers. 4wd local transport where required. Airport transfers.

Safety: The field trip is led by Prof Jonathan Redfern and academic staff /researchers from NARG, who have been undertaking research in Morocco for more than 15 years. Full HSE compliance, with emergency response procedures. All outcrops have been visited and assessed for safety. Hard hats, high-vis vests provided, full medical kits on board coaches. Details of local hospitals provided. Local authorities informed of our planned routes. Daily HSE briefings and reporting.

Who should attend: Suitable for both new hires and experienced geologists /engineers.



Previous Course Attendees :
*Repsol, Shell, Burlington, BG, Hess,
Anadarko, Wintershall*

Devonian Mud Mounds





Itinerary:

Date	Agenda	Accommodation
Sun Nov 10th	Arrival Casablanca /Rabat <i>Introductory Presentation / HSE</i>	<i>Rabat</i>
Mon Nov 12th	Rabat to Errachidia Transect High Atlas Mesozoics Regional Tectonic Evolution	<i>Errachidia</i>
Tue Nov 13th	Errachidia to Erfoud Ordovician Glaciogenics / Silurian Tizi Ou Mekhaz	<i>Erfoud</i>
Wed Nov 14th	Hamar Laghad Devonian Mixed clastic carbonate and Mud-mounds Modern dunes – Erg Chebbi	<i>Erfoud</i>
Thurs Nov 15th	Erfoud Silurian Source Facies	<i>Errachidia / Midelt</i>
Fri Nov 16th	Kerrouchen , Triassic Continental clastics	<i>Khenifra</i>
Sat Nov 17th	Kerrouchen Basin , Triassic Red Beds Drive to Rabat / Casablanca	<i>Casablanca / Rabat</i>
Sun Nov 18th	<i>Depart Morocco</i>	

Cost:

Price is £3450 per person plus VAT, payable in advance
 Price is inclusive of field guide, airport transfer, single room accommodation, all meals and local transport. Price excludes flights to and from Morocco, drinks and other incidentals.

