



Fieldwork

Updates on field studies. Extensive logging and sampling of sections in the Agadir and Tarfaya Basins

Conferences

Presentations made at EAGE, IAS, AAPG, PESG/HGS Africa Conference. Publication update.

New Start PhDs

Nawwar Al-Sinawi joined in April, to work on diagenesis of Jurassic. New Provenance PhD to start in Sept.

Integrated regional studies focussed on the North Atlantic margin

11 PhDs, supported by leading academic staff at Manchester, TuDelft and collaborating institutions

- NARG continues to expand the North Atlantic study, with 11 PhDs in 2016 working on integrated projects along the Moroccan margin.
- We are refining the biostratigraphy of the Early Cretaceous and Jurassic to develop type sections and paleoenvironmental models.
- Seismic and well data supplied by ONHYM allows extension offshore with the aim of developing a fully integrated source to sink study. This includes modelling the complex salt tectonics and evaluating the evolution of the Cretaceous basins.
- New PhD projects will commence this year to extend the reconnaissance work by defining the provenance of the Early Cretaceous clastics and extending the Jurassic study to include the diagenesis, a key factor in determining reservoir characterisation.
- The Cenomanian-Turonian source rock study aims to better understand controls on TOC richness comparing Atlantic margin and Tethyan realms.
- Research has been presented at recent conferences at the EAGE, IAS and AAPG.
- We continue to strengthen our capability, building links with Luc Bulot at Marseille and now involving Mike Simmons (Halliburton) to add biostratigraphic capacity.

New papers on Illizi Basin



English, K.L., Redfern, J., Bertotti, G., English, J., and Yahi Cherif, R., 2016, Intraplate uplift: new constraints on the Hoggar dome from the Illizi basin (Algeria): Basin Research, p. 1-17.



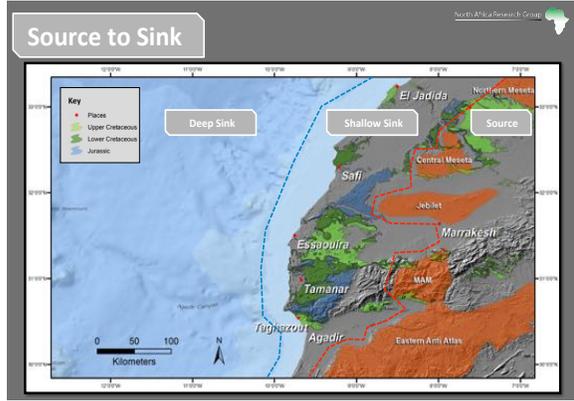
Essaouira Agadir Basin

Barrage outcrop, east of Tamri. Prominent incision into early Barremian limestones filled with fluvial sandstone – Incised Valley?

Defining Late Barremian to Aptian Regressive Packages

Tim Luber completed a 6-week field season focused on improved dating and chasing the coarse clastics interval observed in the Assaka and Tamri outcrops regionally across the Cap Ghir/Agadir/Taghazout region.

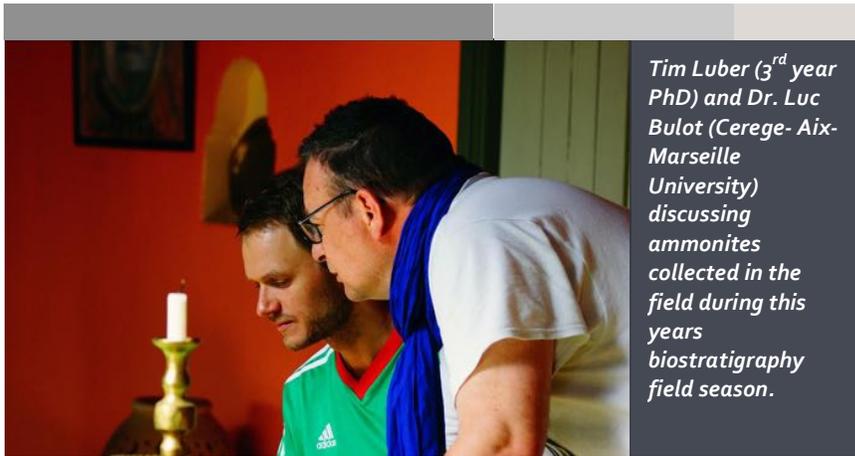
The main fluvial systems were identified inland, associated with the deltaic and shoreface successions. Inland valuable new data points show the extent of channels and incised valleys, which will be input into a regional sequence stratigraphic model. Output will be regional correlations, sequential GDE maps and a revised biostratigraphy.



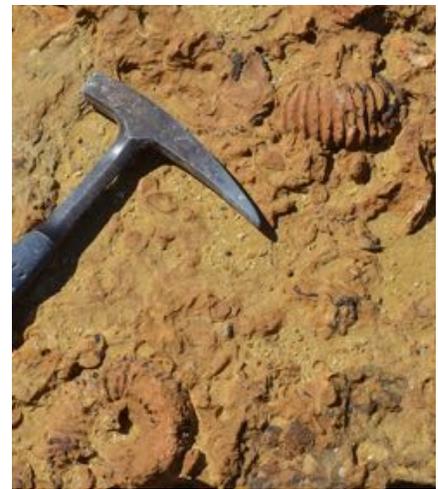
Early Cretaceous Source to Sink Study

Manchester students Angel Arantegui and Tim Luber have completed field seasons supported by a team of field assistants and staff. This is being integrated with analysis of the hinterland uplift / subsidence history by Remi Charton at TuDelft, supervised by Prof Giovanni Bertotti and Prof Joep Storms and offshore subsurface studies by Leonardo Muniz-Pichel and Tu Anh Nguyen.

The outcrop work forms the crucial shelfal control on timing and palaeofacies distribution for the Source-to-Sink study, yielding valuable information on drainage size, location and sediment discharge.



Tim Luber (3rd year PhD) and Dr. Luc Bulot (Cerege- Aix-Marseille University) discussing ammonites collected in the field during this years biostratigraphy field season.



Aptian Reference Section for the Agadir-Essaouira Basin

Further work carried out in March 2015 with Dr Luc Bulot (Cerege - Aix-Marseille University) targeted the ammonite biostratigraphy of key E. Cretaceous sections located in the region. The faunas collected in 2015 and 2016 represent the largest bed by bed collection made in the northern part of the Essaouira basin for the Late Barremian to basal Albian part of the succession. The first paper, being prepared now, will formally describe new ammonite species/genera and establish a biostratigraphic reference to allow refined correlations at basin scale.

High-resolution sampling will integrate ammonite, planktonic foram and nannoplankton dating with TOC and C₁₃ isotopes (bulk rock) data to produce a reference section and greatly improve the chronostratigraphic framework for the Aptian of the Essaouira Basin. This work also involves collaboration with Dr. Mike Simmons (Halliburton) - planktonic foraminifera, Dr Jason Jeremiah (Shell) nanoplankton, and our colleague (previously with NARG in Manchester) Dr. Stephane Bodin (Aarhus University) for carbon/oxygen isotopic analysis.

Blue Aptian marls outcropping at Tiskatine, the proposed location for a new type section in the Essaouira Agadir Basin (top).

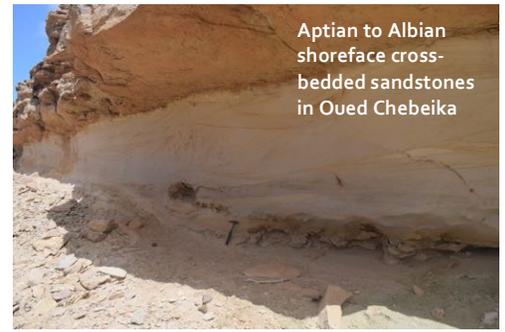
Aptian Procheloniceras sp. ammonites from Tiskatine (bottom).

Tarfaya Study Area

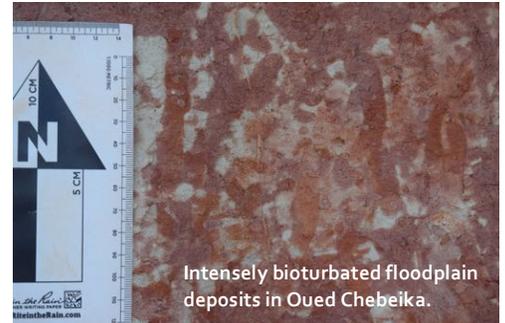
Angel Arantegui undertook five weeks of fieldwork during April and May 2016, supported by Dr Rhodri Jerrett and field assistants. The main focus was logging a 25 km-long transect along Oued Draa, which records the Early Cretaceous continental to marine transition, and runs parallel to the existing transect logged along Oued Chebeika about 50 km to the SW. The aim is to establish an outcrop-based correlation and suite of facies models for the Early Cretaceous succession.

Resampling was undertaken to improve the biostratigraphic dating through macro- and microfossils and palynology. Current work includes microfacies characterization of the re-dated Jurassic mixed siliciclastic-carbonate marine succession in the Ifni area, working in collaboration with Mike Simmons and Luc Bulot, in order to more precisely date this section and document the rift and post-rift evolution of this part of the Tarfaya Basin. Future work will focus on interpreting and integrating all the outcrop and offshore subsurface data:

- Rift to post-rift evolution and sedimentation of the northern part of the Tarfaya Basin
- Early Cretaceous sequence stratigraphic framework -Tarfaya Basin



Aptian to Albian shoreface cross-bedded sandstones in Oued Chebeika



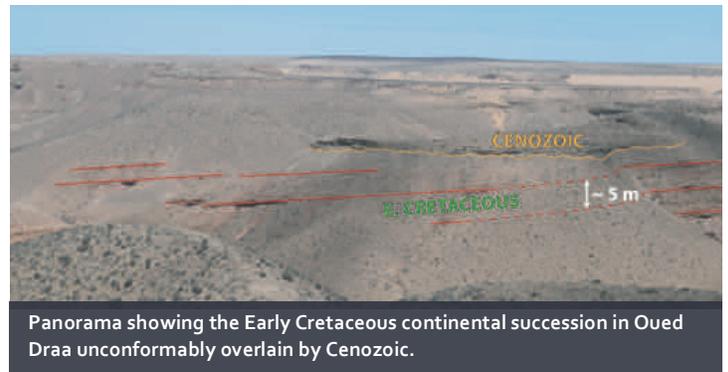
Intensely bioturbated floodplain deposits in Oued Chebeika.



argh....the path is closed..... Dr Rhodri Jerrett at rush hour in Tarfaya

IAS 32nd Meeting of Sedimentology (Marrakech, May 2016)

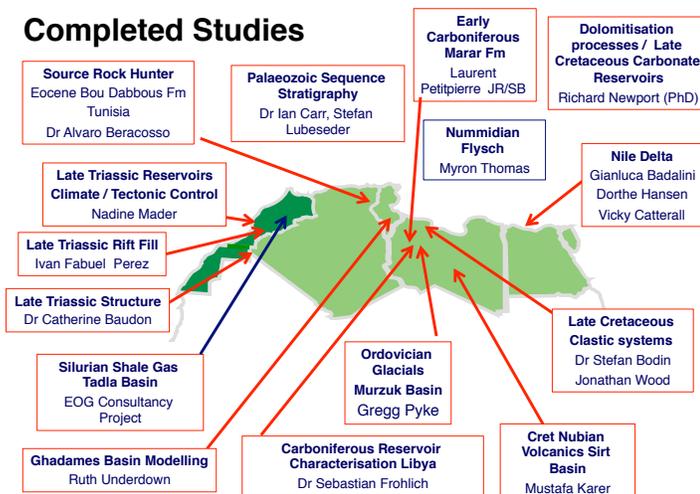
Temporal and spatial evolution of Mesozoic drainage systems feeding the deepwater Atlantic passive margin of Morocco: Tarfaya Basin
Angel Arantegui, Luber T, Charton R, Simmons M, Bertotti G, Redfern J



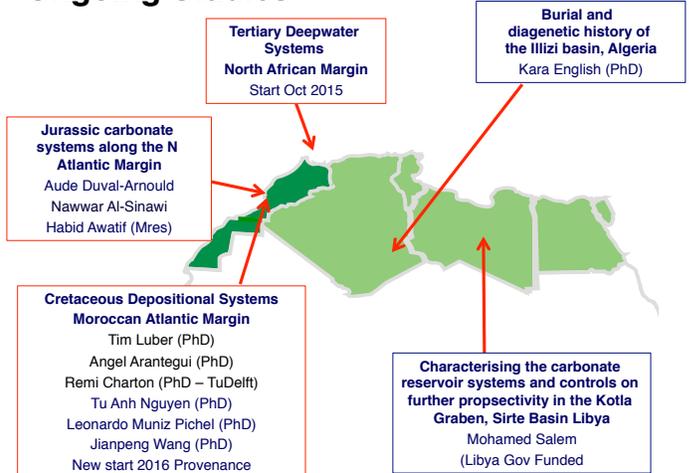
Panorama showing the Early Cretaceous continental succession in Oued Draa unconformably overlain by Cenozoic.

Completed and Ongoing studies in NARG

Completed Studies



Ongoing Studies

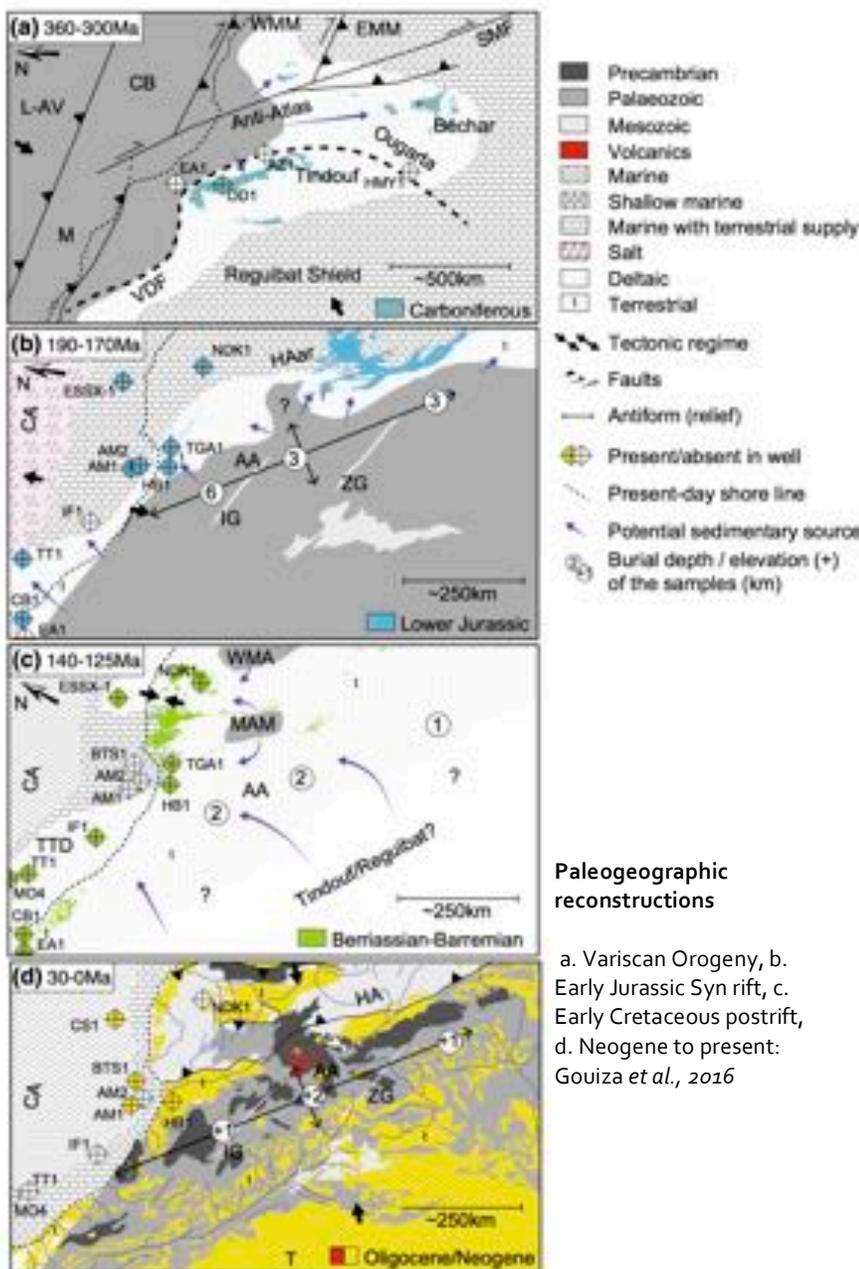


Constraining hinterland dynamics

Quantification of Mesozoic vertical movements

The aim of this work being undertaken by Remi Charton at TuDelft is to provide rates of denudation and subsidence for the exhuming and subsiding parts, respectively. These rates, when extended to surfaces, will provide qualitative estimates of eroded and deposited volumes of sediments for time periods, and can be compared in order to test different scenarios (identification of components and comparison of order of magnitude).

The scenarios to be tested are: a) different extents of the areas being exhumed (by varying the surface); for instance by including or not the Tindouf basin in the exhuming part, or diminishing the eroded surface of the Meseta; b) different timing of erosion (by changing the time-temperature results used for denudation rate calculation); with for instance the complete hinterland (Meseta, Anti-Atlas, and Reguibat) being exhumed during the Early Cretaceous or only the Meseta and the Reguibat Shield (cf. outcome of



Paleogeographic reconstructions

a. Variscan Orogeny, b. Early Jurassic Syn rift, c. Early Cretaceous postrift, d. Neogene to present: Gouiza *et al.*, 2016

Recent Presentations

AAPG/SEG International Conference and Exhibition (ICE) 2016, Barcelona, April (3-6) 2016 – Oral presentation: *Post-Variscan thermal histories in Morocco: Implications for Mesozoic source-to-sink systems* (Rémi Charton, G Bertotti, J Storms, M Gouiza, A Arantegui, T Lubber, A Duval Arnould, and J Redfern).

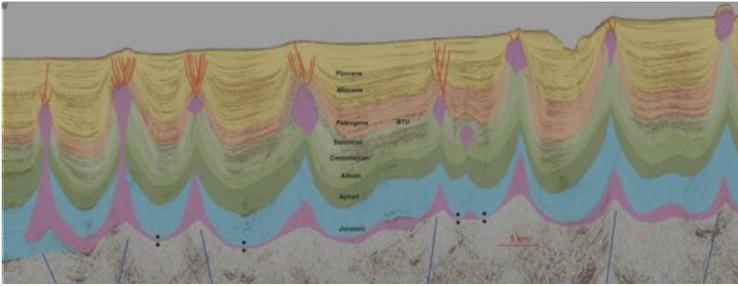
NAC 2016, 13th Nederlands Aardwetenschappelijk Congres, Veldhoven, April (7-8) 2016 – Poster presentation: *Post-Variscan vertical movements in Morocco: Implications for Mesozoic source-to-sink systems* (Rémi Charton, G Bertotti, J Storms, M Gouiza, A Arantegui, T Lubber, A Duval Arnould, and J Redfern).

The Anti-Atlas belt of Morocco extends ENE–WSW, over more than 600 km, from the Atlantic margin in the west to the interior of the African plate in the east. It exhibits Precambrian rocks outcropping as basement inliers and surrounded by marine Ediacaran–Cambrian sequences around the axis of the mountain range. The belt, which has for a long time been interpreted as of Variscan age, is now revealed to have experienced major vertical movements through Mesozoic and Cenozoic times.

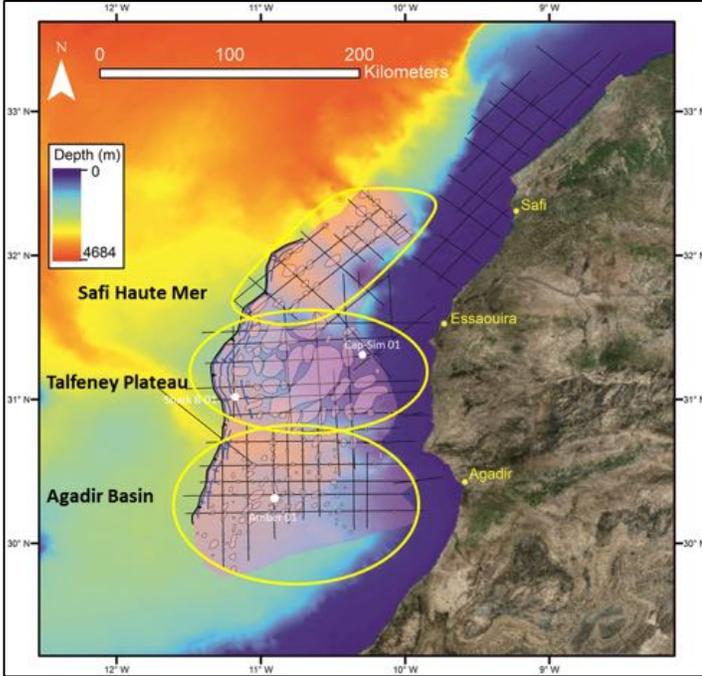
The Anti-Atlas domain appears to be affected by two episodes of exhumation separated by an episode of subsidence. The initial episode occurred in the Late Triassic and led to the exhumation of 7.5–10.5 km of crustal rocks by the end of the Middle Jurassic (ca. 160–150 Ma). The following phase resulted in 1–3 km of basement subsidence and occurred during the Late Jurassic and most of the Early Cretaceous. The basement rocks were then slowly brought to the surface after experiencing 2–3.5 km of exhumation throughout the Late Cretaceous and the Cenozoic.

The timing of these episodes of exhumation and subsidence coincides with major tectonic and thermal events in relation with the evolution of the Atlantic and Tethys Oceans, indicating that the effects of their rifting and drifting extended beyond their presumed margins. 2016





Integrated offshore studies, supported by ONHYM with access to well and seismic data



SALT TECTONICS OFFSHORE MOROCCO: INSIGHTS FROM SEISMIC INTERPRETATION AND DISCRETE-ELEMENT MODELLING

Leonardo Muniz Pichel, Mads Huuse, Emma Finch, Jonathan Redfern

Salt-related deformation plays an important role in the geological evolution and structural style of the Moroccan continental margin and is a critical factor controlling reservoir distribution, migration pathways and trap formation.

The majority of hydrocarbon plays offshore Morocco are salt-related (Tari & Jabour, 2013). This study evaluates how the salt structures evolved and the effect on depositional style and overburden architecture.

Leonardo has presented his initial results at the AAPG/SEG International Barcelona, IAS 32nd Meeting of Sedimentology (Marrakesh) and 78th EAGE Conference and Exhibition workshop in Vienna. His first paper is currently in preparation.

Leonardo's research uses an interactive seismic stratigraphic and forward modelling approach, with Discrete-Element Techniques utilising in-house software and code developed by Dr Emma Finch, to characterize salt-related deformation and model the salt tectonics and associated sedimentation.

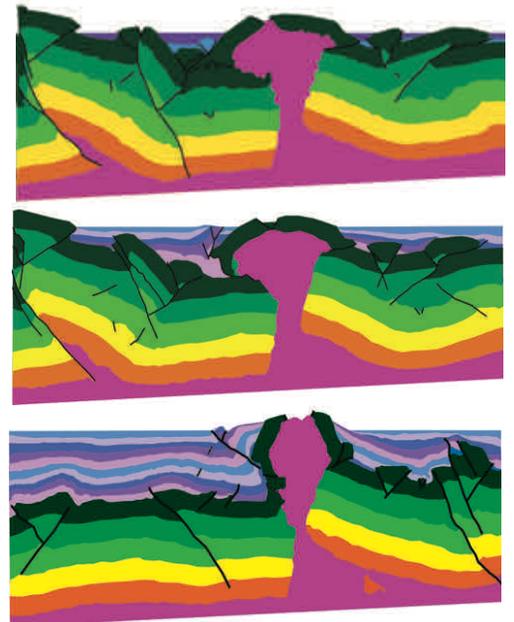
Integration on interpretation of extensive 2D seismic grid and well data supplied by ONHYM with forward modelling of salt deformation affords better constraints on back-stripping the margin evolution and allows for more confident input into petroleum systems models, allowing a spatial and temporal reconstruction of fluid expulsion, migration and accumulation.

Early Cretaceous Basin Configuration

Tu Anh Nguyen (Schlumberger Scholar) is mapping the extensive 2D seismic dataset provided by ONHYM and focussing on the evolution of the Early Cretaceous offshore basin. This interval is the most prospective for potential clastic reservoirs, based on our onshore studies. Timing of salt movement, structural controls and sediment input points all control accommodation and will effect dispersal of Early Cretaceous sediments into the basin. Our aim is to assess these processes and address uncertainty in locating potential sites for ponding of deepwater sandstones.

GIS Database

A programme is ongoing, with a pilot study initiated by Carmen Fiedler and Kofi Owusu to develop a GIS database that will incorporate the extensive field data (samples and analytical results) acquired by NARG, integrated with published data across the region.



Numerical modelling showing rejuvenation of a buried diaper, assumes 20% of compression with syn-kinematic sedimentation (5 M. yr.).

Jurassic Study

Unlocking the depositional style, evolution and diagenetic history of Atlantic Margin Carbonates



Clinoforms build out from Oxfordian reef



Imouzzer Anticline - looking south

Building a stratigraphic and sedimentological framework

Fieldwork by Aude Duval –Arnould (2nd yr PhD) in March focused on the Middle and Upper Jurassic (Oxfordian). Detailed logging of sections providing evidence of the continental / marine/ continental transition. The Upper Oxfordian, Iggui-El-Behar Formation shows evidence of gypsum and storm deposits. Coral reefs have been examined between Cap Ghir and Tizgui/Imouzzer and on the NE limb of the Imouzzer Anticline.

Subsurface analysis of well data is also being undertaken by Awatif Hafid, (ONHYM) as part of her MRes at Manchester, and will be integrated into the study.

Recent conference presentations:

PESGB - Africa Conference 2015 (Sept): Controls on stratigraphic development and reservoir distribution of shelf margin carbonates: Jurassic Atlantic margin - western Morocco. *Duval-Arnould, A., Habid, A., Schröder, S., Redfern, J*

IAS - IMS 2016 (May): Evolution and facies variation of shelf margin carbonates of the Agadir-Essaouira Basin: Middle to Upper Jurassic Atlantic margin - western Morocco. *Duval-Arnould, A., Schröder, S., Redfern, J*



Christian Kluge from TU Delft working with Aude near Imouzzer

Callovian an Oxfordian platform and reefs

A key aim is to characterise the Ouanamane Formation, which comprises very fossiliferous beds of wackstone to rudstone alternating with more marly units. Hardgrounds have been identified that can be widely mapped, suggesting a possible useful correlation tool. A transitional transgressive unit comprises marls with rare belemnites, nautiloids and ammonites. The overlying Tidili Formation has been logged in detail to characterise the distribution of reefal and associated facies. Field logging around the Imouzzer Anticline, together with thin section analysis, is allowing identification of the geometry and extension of the build-ups. This is being extended to the Cap Ghir area and a biostratigraphic plan formulated to better date these sections, in conjunction with Luc Bulot and Mike Simmons. Different generations of reefs have been identified, with specific coral associations linked to the size of the build-ups and the prevailing environmental conditions.

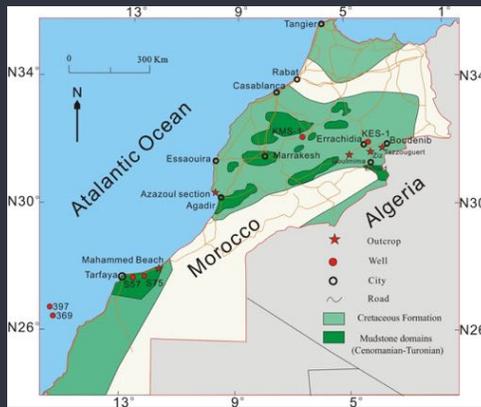
Extending the study:

Nawwar Al-Sinawi, (supervisors: Hollis, Schroeder, Redfern) started a PhD in April 2016 working on dolomite formation in the Jurassic of the Western High Atlas. Dolomitization plays a key role in subsurface reservoir development offshore Morocco and the conjugate margin in Canada, yet the exact origins and processes for dolomitization are not understood, nor has the impact of dolomitization on subsurface reservoir development been explored.





PhDs and Postdocs from Manchester and Leeds (NARG/STRAT Groups) examining late Cretaceous karst surface and OAE 2 in Azazoul. Morocco.



Source Rock Hunter- Controls on Cenomanian-Turonian source facies development

The project is undertaken in collaboration with ONHYM, through Directeur de l'Exploration Pétrolière M. Mohamed Nahim and Chakor Alami, Chef de la Division des Laboratoires Pétrole. In April Zakaria Yousfi from Onhym accompanied Jianpeng in the field. Sections logged and sampled to assess depositional variability and controls, and determine a type section for the OAE2 Cen- Tur section.

Black shales (weathering light tan) from Turonian of Erachidia .



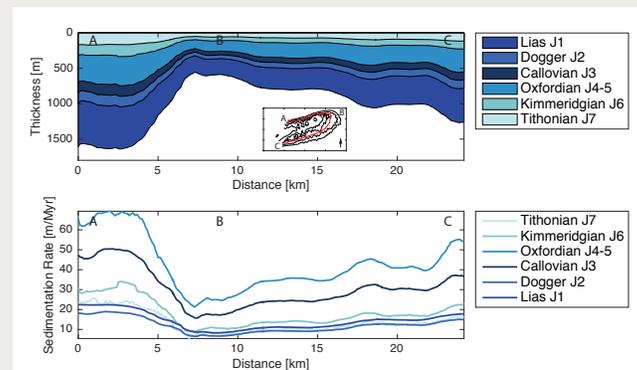
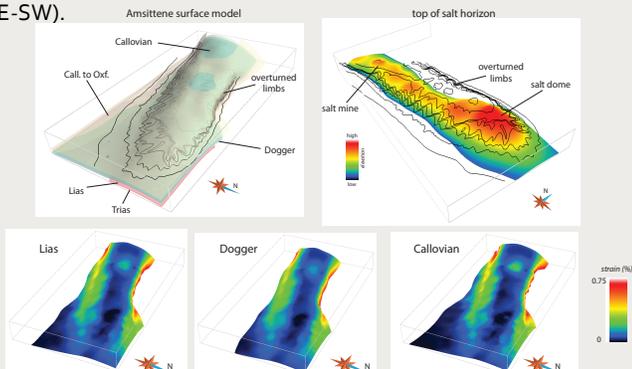
PhD Jianpeng Wang is undertaking a regional evaluation of the OAE2 interval that spans the Cenomanian-Turonian to examine depositional controls on source rock development, comparing the development along the Tethyan and Atlantic margins.

Controls on Structural development: Christian Kluge –Tu Delft Masters Project

How can the formation of Mesozoic anticlines in the Western High Atlas (WHA) be linked to vertical movements in the Moroccan passive margin and did their evolution in the Jurassic (prior to Alpine shortening) influenced sediment distribution in the offshore? Was salt driving force in the folding process and, if folding occurred during pre-orogenic stages, what was its impact on folding processes during the Atlasic orogeny.

Two 3D structural models (Amsittene & Imouzzer anticline) have been created from remote sensing data to obtain the thickness distribution of sediments in the anticlines. Possible depocenters were evaluated and pre-Alpine fold orientations identified that might vary from the present day strike. The top of salt horizon was modelled to understand relative positions of salt domes. 2D restoration was performed in order to reveal tectonic signals within the Jurassic and finally a 3D model was analysed to assess the highest strain within a fold. The large scale modelling results have been compared to small scale field observations (from work by Aude Duval –Arnould, Manchester).

The results show that folding processes might have already been active during Early to Middle Jurassic. Salt diapirism is seen to be a key factor in pre-orogenic fold growth, possibly creating a topography already in the Early to Middle Jurassic. Folds in the WHA are therefore seen to have controlled the distribution of sediments coming from the hinterland and may effect submarine fan deposition offshore. Still, their impact on the formation of minibasins may not be as significant compared to the present day offshore folds caused by later, much stronger and more continuous salt diapirism. Linking vertical movements to Jurassic folding processes is still difficult, since no clear evidence for N-S striking folds due to the exhumation in the East and subsidence in the West, have been found. However, pre-existing salt diapirs presumably controlled the Alpine folding process, by connecting pre-existing salt structures causing a variety of strike orientations of Alpine folds in the WHA (from E-W to NE-SW).



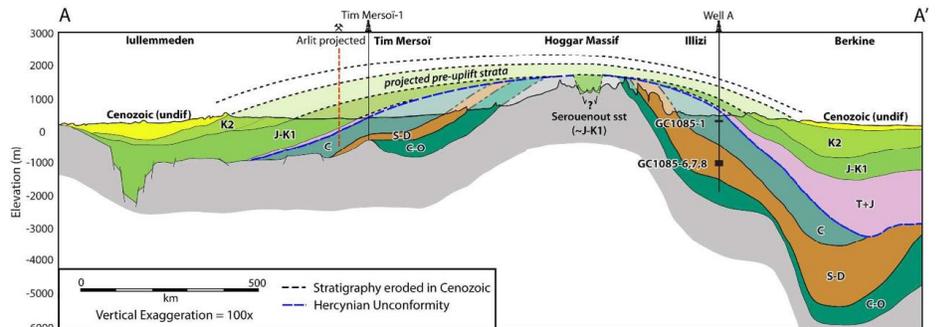
Subsurface studies continue across the North African region

The current political / security situation is preventing fieldwork across much of North Africa, with the exception of Morocco, however subsurface studies continue, and further integrated projects are being planned, both onshore and offshore.

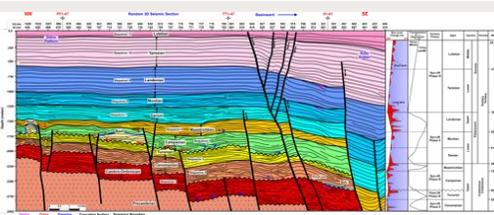
Diagenesis and thermal history of the Illizi Basin during the Ordovician, Algeria.

Kara English (Final Year) has worked 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 have been used to constrain the thermal and burial history of the Ordovician reservoirs in the Ain Tsila field.

Techniques employed 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 allow prediction of 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. The burial history models are utilized in order to construct some conceptual sandstone diagenesis models using Touchstone™ software, and to determine the (spatial and vertical) variation of reservoir quality across the Ain Tsila field, with significant implications for exploration across the basin. *See publications section for list of papers.*



Schematic structural section across the Hoggar Massif from the Berkine Basin in the north to the Iullemeden Basin in the south: from English et al 2016

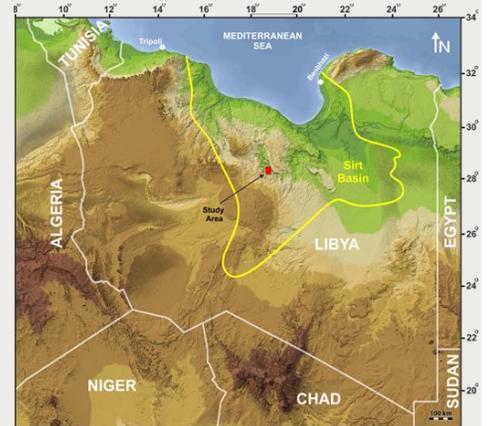


Interpreted geological model integrating wells and 3D seismic to identify the chronostratigraphic sequences. Sea level change curve, shows the regressive-transgressive cycles and observed seismic reflection patterns.

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

Mohammed Salem (Final year) Libyan Government funded, data supplied by AGOCO:

The evolution of the Western Sirt Basin in the region of the Dahra Platform, Amin High and Kotla Graben is being evaluated, integrating 2D / 3D seismic and data from 36 wells. Three tectonic styles identified include regional pre-rift intra-continental sag, complex multi-stage rifting and modification by wrenching. A major horst-graben system configuration has been delineated, which allows mapping fault distribution and timing throughout the area. These maps are being used to interpret the tectonic style and evolution and its control on accommodation, thickness and facies distribution of reservoirs throughout the Dahra Platform and Kotla Graben area.



Plans underway for 2016-7

Planning is underway for a new integrated project in Mauritania and along the west Africa Atlantic margin. Further projects onshore Morocco are anticipated, looking at the development of the Nummidian Flysch across the Alboran Basin and onshore NE Morocco, in collaboration with Tangiers University.



Recent Publications and Upcoming Conference Presentations

Published:

English, K.L., Redfern, J., Bertotti, G., English, J., and Yahia Cherif, R., 2016, Intraplate uplift: new constraints on the Hoggar dome from the Illizi basin (Algeria): Basin Research, p. 1-17.

English, K.L., Redfern, J., Corcoran, D.V. English, J., and Yahia Cherif, R., 2016, Constraining burial history and petroleum charge in exhumed basins: New insights from the Illizi Basin, Algeria. AAPG Bulletin, v. 100, No. 4 (April), p. 623-655.

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)

Submitted:

English, K.E., English, J.M., Bonnell, L., Lander, R.H., Hollis, C., Redfern, J., Guirdham, C., Garnham, J., Yahia Cherif, R., Controls on reservoir quality in an exhumed basin (Ordovician sandstones, Illizi basin, Algeria). Marine and Petroleum Geology.

English, K.E., English, J.M., Hollis, C., Redfern, J., Corcoran, D., Oxtoby, N., Yahia Cherif, R., Remobilization of Deep Basin Brine during Exhumation of the Illizi Basin, Algeria. Marine and Petroleum Geology.

English, K.E., English, J.M., Hollis, C., Redfern, J., Corcoran, D., Oxtoby, N., Yahia Cherif, R., Remobilization of Deep Basin Brine during Exhumation of the Illizi Basin, Algeria. Marine and Petroleum Geology.

Upcoming presentations:

PESGB-HGS Africa Conference: Houston Sept 2016: *Predicting the development of source rocks in carbonate-dominated settings – A case study from the Eocene Bou Dabbous Formation (north and central Tunisia)* Jiménez Berrocoso (Repsol Services Company, USA), J.D. Wood (Shell, Netherlands), M. Soussi (Université de Tunis, Tunisia), H. Belayouni (Université de Tunis, Tunisia), and J. Redfern (University of Manchester, UK).

AAPG: Calgary June 2016: *Mitigating Early Cretaceous reservoir risk along the offshore Morocco passive margin through analysis of the coastal delivery systems exposed in the Agadir-Essaouira Basin.* Tim Lubber, Redfern J, Bulot L, Arantegui A, Charton R, Bertotti

New for 2016:

Provenance study of the Early Cretaceous depositional systems, Agadir and Tarfaya Basin

This project was approved in January to commence in September 2016. It will apply an array of techniques, including heavy mineral analyses, zircon, and feldspar to assess the possible provenance locations and contribution history for the Early Cretaceous depositional systems, linking existing work being undertaken on the sedimentology on the margin and Fission Track modelling of potential source areas. To be conducted in collaboration with Dr Shane Tyrell, UCD / Galway University, Eire.

Morocco Field Workshop

The last NARG field workshop in 2015 was attended by Cairn, Chevron, Hess, Repsol, Kosmos and ONHYM, examining the evolution of the North Atlantic margin. The entire sequence is exposed, from Pre Hercynian through to Triassic rift infill, Jurassic passive margin carbonate development and Early Cretaceous deepwater systems / source to sink.

A further course is planned for late 2016-early 2017, *Open to all companies, contact Jonathan Redfern*



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 Dr David Hodgetts
 Dr Rhodri Jerrett

PhDs:
 Tim Lubber
 Angel Arantegui
 Mohamed Salem (Libyan Gov. Sponsors)
 Tu Anh Nguyen (*Schlumberger Scholarship)
 Aude Duval –Arnould (Manchester)
 Jianpang Wang (Chinese Gov. Scholarship)
 Leonardo Muniz-Pichel (Brazilian Gov)
 Kara English (Manchester)
 Nawwar Al-Sinawi

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 Dr Mike Simmons (Halliburton)
 Dr Stephane Bodin (Aarhus University)
 Dr Dorrik Stow (Heriot Watt University)
 Dr Jason Jeremiah (Shell)
 Dr Shane Tyrell (UCD / Galway University)