



North Africa Research Group

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www.narg.org.uk



View across the Argana Basin, Morocco

Fieldwork

More Early Cretaceous sections logged and sampled in Morocco for facies and provenance

Triassic Synrift in Eastern Morocco – regional provenance study

New Projects

Regional Tectono-stratigraphy of MSGBC – utilising Petrosen and TGS seismic data

New Sponsors

Hunt Oil, Mazarine Energy and Shell join in 2019

New Starts

Ian Mounteney starts MPhil examining Cretaceous clastic provenance in Senegal

Pierre-Olivier Bruna joins as PostDoc working on fractured reservoirs- Tunisia

Results coming in from Senegal Provenance Study

As part of a suite of projects in Senegal and the MSGBC, in collaboration with Petrosen and TGS, we are undertaking a regional source to sink study, with MPhil student Ian Mounteney, working at the BGS.

Sampling was completed in 2019, with 135 core/cuttings from 19 wells across Senegal (Silurian, Devonian, Early/Late Cretaceous and Palaeogene). Modern river samples were also collected for comparison. In total 32 kg of core/cuttings/sand produced 4 kg of fine (63-125 micron) sand. Results are expected shortly. See page 5.

New Projects

NARG is constantly starting new projects. In 2019 we move back to Tunisia, to begin reservoir characterisation studies with the appointment of Dr Pierre-Olivier Bruna at Tu Delft. We also have plans in place to undertake new studies in Libya and Egypt in 2019/20.

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TGS Seismic MSGBC Basin Study

A new PhD will commence in 2019 to examine the regional Tectono-stratigraphy of the MSGBC Basin undertaking regional mapping and integrating well data provided by Petrosen with regional seismic data provided by TGS and Spectrum. This build on existing reconnaissance biostratigraphic work and results from examining 3D seismic donated by TGS in The Gambia.



Welcome to our New Sponsors



NARG

- 20 years of experience working across North Africa
- Over 10 Academic s, 3 PostDocs and 6 PhDs, 2 MSc/MRes students
- Global collaborations with leading specialists
- Working with local institutions
- Active projects underway in Morocco, Senegal, Mauritania, Tunisia, Egypt, Central Atlantic
- Projects cover all aspects of the petroleum system: Depositional fairways, source to sink, clastic and carbonate sedimentology, reservoir characterisation, thermo-geochronology biostratigraphy, landscape evolution and modelling

The Africa Experts

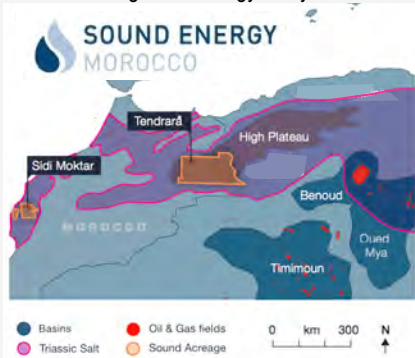
Triassic Source to Sink Eastern Morocco



After successfully completing his MSc by Research in September 2018, James Lovell-Kennedy, has now commenced a PhD into the provenance of the Triassic fluvial reservoir (TAGI) in Eastern Morocco. During the first year of the PhD, alongside training provided by the NERC CDT Oil and Gas, he undertook further field and core sampling season in November 2018. More samples have been collected from the Kerrouchen Basin, Middle Atlas, and from wells drilled in the High Plateau. In addition we have been generously donated data from the Tendirara Block by Sound Energy.

These samples are being analysed for petrographic and heavy mineral signatures and a representative sample selected for detrital zircon geochronology analysis at the London Centre for Geochronology in late 2019. These provenance data points will be integrated with the ArcGIS database

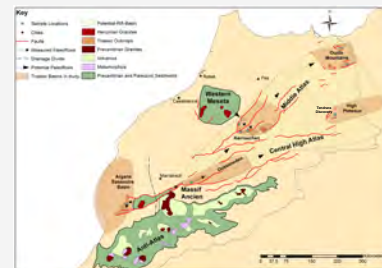
As a precursor to the Triassic provenance study, a meta-analysis has been performed upon all published detrital zircon studies as a way of informing which detrital zircon populations are provenance indicators and the number of grains required to confidently identify these populations. Also, work has been undertaken with Dr Remi Charton and Emmanuel Roquette into a systematic review of Moroccan source to sink systems based on all currently available dataset.



The Triassic syn-rift continental clastics were deposited at the onset of rifting. They are proven reservoirs in the Essaouira Basin and the recent Sound Energy gas discovery in Tendirara, on the High Plateaux, has re-invigorated interest in the play.

The reservoirs are tight fluvial sandstones and a key factor is to better understand reservoir quality and distribution.

The system has potential offshore on both conjugate Atlantic margins where there is limited overburden.



Presentations:

EGU Vienna, April 2019 – 'Utilising multi-proxy provenance techniques to reconstruct local vs regional drainage networks of Central Pangea during the Upper Triassic'

Poster at PESGB Africa, October 2019 – 'Modelling Depositional Systems across Morocco – the limitations of using detrital zircons in understanding source to sink systems'

Work completed to-date:

- Fieldwork in the Kerrouchen Basin, logging and sampling for provenance, loaded on GIS Database
- Petrographic analysis of samples from the Kerrouchen Basin, Oukaimeden Basin and Tendirara Basin
- Vintage wells sampled at ONHYM
- Heavy Mineral separation and grain mount preparation
- Raman Spectroscopy will be used to perform analysis to simultaneously gather abundance and varietal data of heavy minerals for provenance analysis
- Analysis of well, seismic and sample data supplied for research by Sound Energy from the Tendirara Block
- Regional meta-analysis of all previous detrital zircon studies

Awards:

James submitted his MRes thesis into the Earth Model Competition, run by Halliburton Neflex and The Geological Society, competing with 70 submissions from around the globe.

James came second and was invited with his supervisor Prof Jonathan Redfern to attend the LIFE Conference in Houston in August, where he was awarded the prize and presented a talk: 'Assessing the provenance and contribution of local vs regional drainage systems for the Upper Triassic fluvial deposits, High Atlas, Morocco'



NARG Publications on the Triassic Systems in Morocco

Mader, N. K. and Redfern, J. (2011). A sedimentological model for the continental Upper Triassic Tadrart Ouadou 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

Redfern, J., Shannon, P.M., Williams, B.P.J., Tyrell, S., Leleu, S., Fabuel Perez, I., Baudon, C., Stolfova, K., Hodgetts, D., Speksnijder, A., Houghton, 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

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.

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.

Mader, N. K., Redfern, J. & El Ouataoui, 2017, Sedimentology of the Essaouira Basin (Meskala Field) in context of regional sediment distribution patterns during upper Triassic pluvial events: In *Journal of African Earth Sciences*. 130, p. 293-318 26 p. DOI: 10.1016/j.jafrearsci.2017.02.012

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.

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.

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

Mauritinide Low-T Geochronology Dataset



Samples have been collected in Mauritania during our field campaign of February 2017 and now in Senegal during a field season in November 2018, in collaboration with UCAD/IST. We have been successfully processed apatites, to be measured for Apatite Fission Tracks and U, Th, He. This is the first consistent set of exhumation ages from the Mauritanides of Mauritania and Senegal

Initial results suggest the “anomalous” exhumation pattern documented in Morocco the measurements is also recorded all down the NW African margin, confirming our working hypothesis that large portions of the passive continental margin experienced exhumation during the post-rift, and that, therefore, could have been the source for the terrigenous sediments targeted by hydrocarbon exploration in the Mauritania offshore.

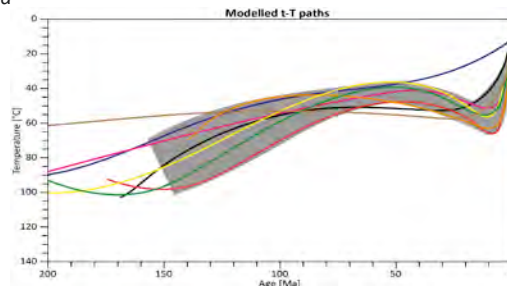
All the results are now being processed and will be presented to our sponsors later this year, in advance of publication. This research, integrated with the ongoing source to sink and provenance studies being undertaken by NARG, and the offshore seismic mapping, provides a unique and very valuable dataset to better understand basin dynamics and the delivery of clastics to the deep basins.



Samples collected in the Mauritanides of Senegal (grey) during the NARG 2019 campaign in Senegal, to complement data already collected in Mauritania. Data screenshot from GIS Database

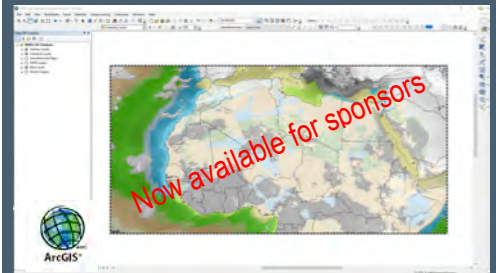


Samples collected during the NARG 2017 campaign in Mauritania



Initial results: time-temperature curves for the analyzed Mauritania samples

GIS Database



- Accessible and secure platform**
A GIS platform accessible online to all members of the NARG: sponsors, researchers and students
- Abundant and reliable data**
Stores and allows access to data collected by NARG PhD students, as well as locations of industry datasets and relevant literature
- Efficient and relevant applications**
Serve as a basis for current and future (i.e. **up-to-date**) research projects conducted within the NARG

Landscape Evolution of the Anti-Atlas, insight using pyBADLANDS

The distribution of eroded sediments on continental rifted margins is controlled by the drainage systems that connect the exhuming and the subsiding domains. Most of these systems are not preserved, resulting in a lack of data for their size, sediment flux and entry point position.

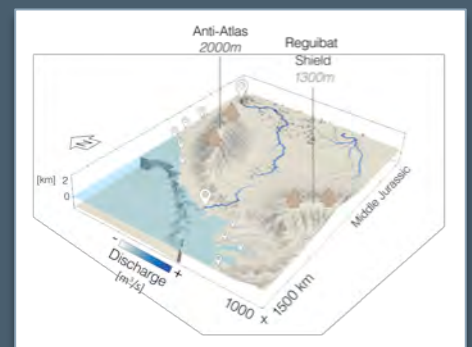
We are using the Landscape evolution model pyBADLANDS, Salles et al., 2017 to examine the drainage systems on the Atlantic margin of Morocco, constrained by the last 6 years research on Cretaceous and Jurassic depositional systems and the extensive LowT Geochronology database and exhumation models developed at TuDelft.

Inputs: Flat initial topography, Precipitation. Exhumation as a proxy for uplift.

Outputs: Sedimentary routing, budgets and entry points; paleo-altimetry

New Research:

- combining ASPECT (geodynamic models) and pyBADLANDS
- combining pyBADLANDS and Delft3D (establishment of the Tan-Tan and Boujdour Deltas)



Building Strong Collaborations

Fieldwork would not be possible without the support of the **Office Mauritanien des Recherches Géologiques** of the I.R of Mauritania. The Director *El Hachemy Ould Sidaty* and the adjunct Director *Abdellahi Ahmedou Bellal* of the OMRG In Senegal fieldwork was supported by UCAD and the Earth Institute, and we also thank **Mr Mamadou Faye** General Manager, Petrosen, and all their staff for continued support. In Morocco we thank **ONHYM** and Exploration Director **Mr Nahim** for continued co-operation.

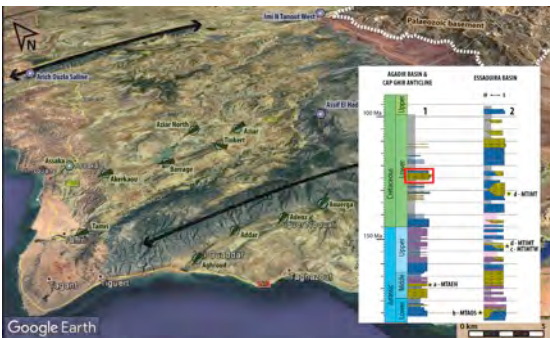
Tristan Salles, Sydney Uni. Code developer of pyBADLANDS.
Frans van Hoeflaken and **David Boote** thanks for the Libya GIS Digital Field Trip
Mohamed Gouiza, Leeds University. Geodynamic numerical modelling of the Central Atlantic with the ASPECT code.
Helena van der Vegt, Deltares. Delft3d modelling.

Provenance Studies



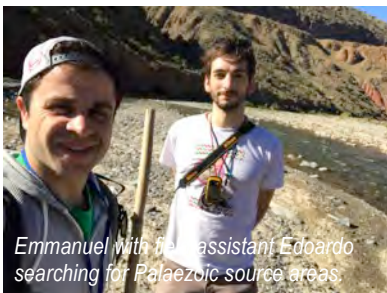
A regional source to sink study of the Jurassic to Early Cretaceous in the Essaouira-Agadir Basin is being undertaken by PhD Emmanuel Roquette. The aims are to: (i) develop a robust regional palaeogeography and tectonostratigraphic model highlighting the evolution from source to sink, (ii) understand the controls, timing and volume of the sediment supply to the margin delivered via fluvial systems and (iii) constrain the importance of sediment recycling, mixing and storage, and how they are influenced by the tectonostratigraphic evolution of the margin (iv) whether differential uplift in the hinterland resulted in a change of sediment sources and reorganization of sediment routing across the margin.

Emmanuel started the PhD in January 2017, building on the work of Tim Luber, who defined the early Cretaceous depositional stratigraphy and facies models and initial concepts on the drainage system. The study also incorporates the low T-geochronology exhumation models developed by Remi Charton at TuDelft, to generate information on potential source areas.

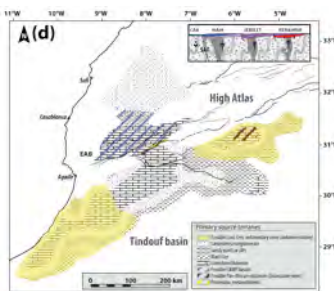


This project applies sandstones petrography and geochemistry (including heavy minerals and zircon geochronology) to trace sandstones provenance and to establish a source-to-sink model for the Mesozoic succession. The project study was extended to the Jurassic to track potential source changes throughout the Mesozoic. Emmanuel has developed a new modelling method to reconstruct palaeogeological maps based on Thermochronology data and 3D interpolation for selected intervals of interest.

Initial results were presented at the Conjugate Margin Conference of Halifax (Jul18) where Emmanuel received the award of best student presentation. The results were also showcased at the EGU conference in Vienna (Apr19).



Emmanuel with his assistant Edoardo searching for Palaeozoic source areas



MaCPA Manchester Centre for Provenance Analysis

The MaCPA (Manchester Centre for Provenance Analysis) is NARG's provenance research pole. The group has 4 key researchers; Remi Charton (PostDoc), Emmanuel Roquette (3rd Year PhD), James Lovell Kennedy (2nd Year PhD) and Ian Mounteney (MRes) and lead by Dr Stefan Schroeder, Prof. Jonathan Redfern and Prof. Giovanni Bertotti.

A complete Heavy Mineral analysis laboratory has been set up at the University of Manchester, comprising of crushing, separating, mounting and analysis capability. A large capacity jaw crusher has been installed, and samples are crushed to 1mm before being dry sieved (with meshes=< 250 µm) and wet sieved (at 30 µm to remove all clays) using disposable nylon meshes to avoid cross contamination.

The heavy minerals separating facilities at Manchester rely on density separation using Sodium Hetero-Polytungstate (density of 2.80 g/cm³) prior to cryogenic recovery of the heavy fraction, using the liquid nitrogen bottom freeze method. Mounts can be made in-house by University technicians or in the case of isotopic dating, by NARG after being hand-picked.

Mineral identification is assessed by QEMSCAN (automated SEM) point-counting and polymorphs identification using Raman-microscopy. Both pieces of equipment are installed within the department.

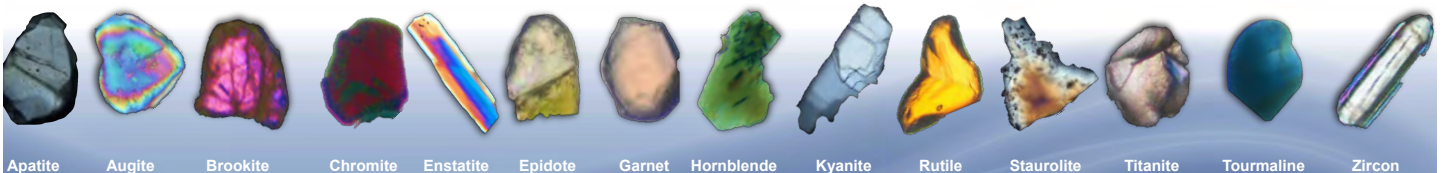
The group has ties with the British Geological Survey, where Ian Mounteney is based and where detrital zircons are dated using laser ablation ICPMS. The group also works with Low Temperature Thermochronology (LTT) data acquired at TuDelft, (Remi Charton and Giovanni Bertotti) in collaboration with partner laboratories in the University of Göttingen.

The group is also working on an integrated provenance study of North Africa compiling datasets of petrographic composition, palaeocurrents, LTT data, detrital zircon ages and heavy minerals from both published and original research.

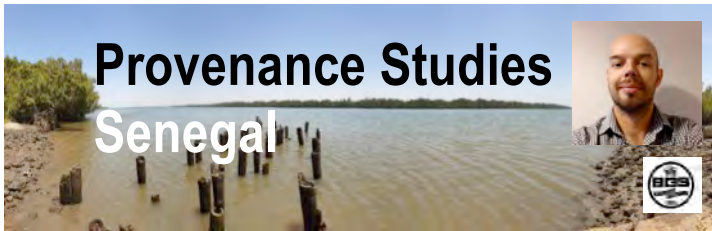


Example of modelled palaeogeography

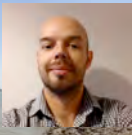
Working in the MaCPA heavy mineral separation lab



Apatite Augite Brookite Chromite Enstatite Epidote Garnet Hornblende Kyanite Rutile Staurolite Titanite Tourmaline Zircon



Provenance Studies Senegal



The provenance of the Jurassic and Cretaceous sediments within the MSGBC basin is poorly constrained; this project aims to identify potential shifts in heavy mineral assemblage, which can be used in stratigraphic correlation and the association between basin sedimentation and hinterland tectonics.

We have established an MOU with Petrosen to access well data onshore and offshore, as part of a collaborative study. Ian Mounteney is undertaking an MPhil at Manchester, whilst continuing to run the BGS labs in Keyworth.

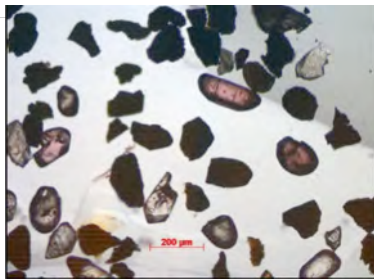
Sampling was undertaken in 2018 and 2019 in their corestore and sands collected include: 135 core/cuttings from 19 wells across Senegal (Silurian, Devonian, Early/Late Cretaceous and Palaeogene),

In addition in April 2019, 9 samples were taken from the modern day river systems (Casamance, Saloum and Senegal), 21 samples from quarries and pits (Quaternary) And 8 from cliff exposures (Late Cretaceous).

Heavy mineral analysis underpins the provenance aspect of this research, with complimentary methods including: clay-mineralogy, whole-rock mineralogy and petrography (Quartz/feldspar/lithic analysis).

Research by numbers: 32 kg of core/cuttings/sand produced 4 kg of fine (63-125 micron) sand, which in turn yielded a total of 50 grams of heavy mineral concentrates. Heavy mineral analysis has been undertaken using optical microscopy, with a total of 190,010 grains observed and 42,218 transparent detrital heavy minerals (tdHM) identified, averaging ~300 tdHM per sample.

We are now in the process of organising and interpreting the results with an aim to produce a first-draft paper on the modern-day sediments by late 2019.



An assortment of zircons (Cretaceous sands) from Senegal



River sampling 2019



Quaternary sands at Thiago Quarry (Northern Senegal)

We acknowledge support for data access and the workshop from:



NARG Senegal Workshop

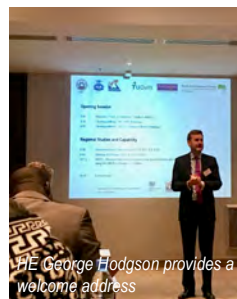
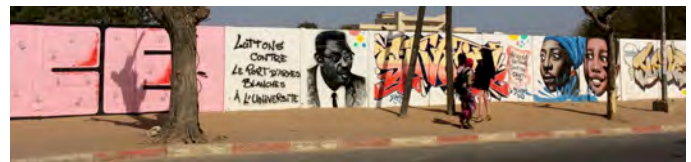


In April 2019 NARG (Prof Jonathan Redfern together with Prof Giovanni Bertotti) from TuDelft ran a 3-Day series of lectures/practicals at the University of Dakar (UCAD) on Petroleum Geoscience, attended by over 30 MSc and PhD students.

This was followed by a successful 1-Day Workshop by NARG to showcase research and build collaboration between academia and industry, supported by BP, TGS and the British Embassy Dakar. The meeting was opened by Mr Mamadou Faye, the General Manager of Petrosen, and a welcome address by the UK Ambassador in Dakar, His Excellency George Hodgson. NARG presented research, with students Max Casson and Ian Mounteney also showcasing their latest work. Other speakers included Simon Hendry from BP, Ben Sayers from TGS and Prof Aziz (IST-UCAD). A very successful event that we hope to repeat next year.



Workshop held on the UCAD Campus Dakar 2019

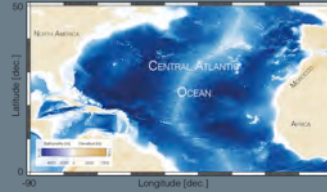


The George Hodgson provides a welcome address



Mamadou Faye, GM of Petrosen

Central Atlantic Evolution



When studying past vertical movements of passive margins, most AFT data has been collected in the unstretched continental crusts, i.e. adjacent to the rifted margins. Often, to explain syn-rift AFT ages, many of the studies assume shoulder uplift and associated erosion. However, the spatial and temporal occurrence of such uplift is variable across present-day cases, and may also be absent.

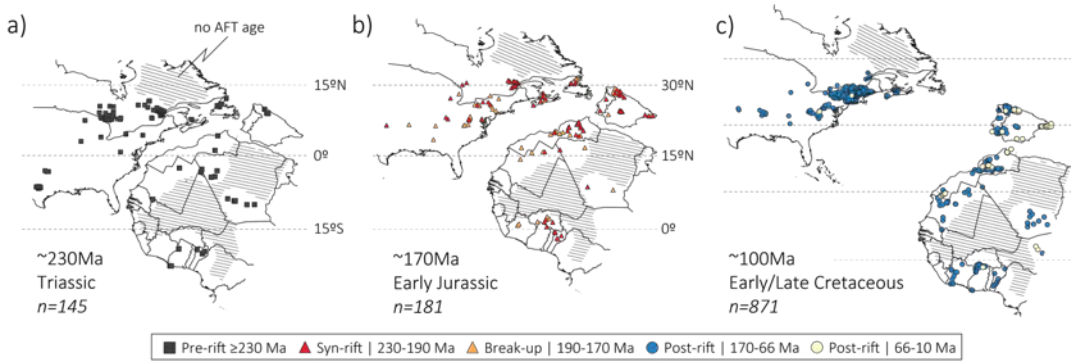
For early post-rift AFT ages, some authors have argued that the rift thermal signature extended beyond the rift zone and affected the geothermal gradient of the continental crust, resulting in a reset of the AFT ages followed by a post-rift cooling (e.g. in Australia, reached out up to 130km away from the passive margin, Moore et al., 1986).

Others assume processes such as far-field stresses, enhanced erosion by climatic/landmass position change, or dynamic topography for instance, either superimposed to rifting thermal perturbation of the apatite crystal or simply as the sole responsible process for exhumation.

In this work, by Remi Charton at TuDelft is using the extensive AFT database (>1000 AFT ages) from the rim of the Central Atlantic Ocean. We aim to define AFT spatial and temporal patterns in regards to the pre- (prior to Late Triassic), syn- (Late Triassic to Early Jurassic), early post- (Middle Jurassic to Early Cretaceous), and post-rift (Late Cretaceous and younger) phases.

In addition, we will run a geodynamic model tailored to the Central Atlantic ocean while monitoring the evolution of the APAZ through time in the unstretched continental crust. We will then combine both sets of observations to submit an update to the conceptual model of passive margin evolution.

In the follow-up work, we will use our existing database of >5000 LTT ages, the results of 4 years of literature review and compilation, and which spans across 4 continents. Combined to that, we will use over 500 published time-temperature curves to reconstruct the vertical movement evolution of the Central Atlantic hinterlands.



Basemap of the Central Atlantic after Muller et al. (2016)'s model extracted from GPlates for a) 230, b) 170, and c) 100Ma with a rectangular projection.

AFT ages are categorized in regards to Central Atlantic rifting events. Onset of rifting and drifting are debated at +/- 20Ma.

Graduation 2019



Some pictures from graduation in Manchester this July. A record I think, with 4 NARG PhDs: Aude, Jianpeng, Angel and Leonardo, plus James graduating with his MRes (and my other PhD Ginny who has also been helping with the GIS Database!



Jurassic Reservoir Characterisation

Investigating the depositional style, evolution and diagenetic history of Jurassic along the Atlantic Margin



Aude Duval-Arnauld successfully completed her PhD in 2019, supervised by Stefan Schröder, Jonathan Redfern and Luc Bulot, working on Jurassic depositional systems and strata architecture.

The first paper: "Evolution of early post-rift depositional systems along the Moroccan Atlantic Margin: the Essaouira-Agadir Basin, Lower and Middle Jurassic" has just been submitted for publication.

Aude is staying with NARG as a PostDoc, working on a new project on the origin and extension of the interbedded upper Jurassic clastics along the Atlantic coast of Morocco. Reconnaissance field work planned for October 2019, extending from the Essaouira-Agadir Basin in the South to the Rif in the North, to observe lateral variations and correlate the upper Jurassic sedimentary packages along the western coast of Morocco.

This aims to better constraints the size and orientation and character of the Oxfordian and Kimmeridgian continental and marine siliciclastic deposits in the overall carbonate-dominated upper Jurassic succession.

Aude will also be finalising the new Callovian-Oxfordian biostratigraphic framework for the Essaouira-Agadir Basin with Dr Luc Bulot, also to be submitted for publication in 2019.

Conference Presentations:

Bathrust Conference (9-11 July 2019): Poster "Tectonic and environmental controls on passive margin carbonate platform development. Jurassic of the Essaouira-Agadir Basin, Morocco." - Duval-Arnauld, Aude; Schröder, Stefan; Bulot Luc; Charton, Rémi, and Redfern, Jonathan

PESGB Africa Conference (1-2 October 2019): Talk " The interplay of carbonate platforms and siliciclastic influx during the Jurassic along the Moroccan Atlantic Margin: Controls and impact on reservoir distribution." - Aude Duval-Arnauld, Angel Arantegui, Rémi Charton, Emmanuel Roquette, Stefan Schröder, Luc Bulot and Jonathan Redfern
Abstract + extended abstract)



Bivavles, Oxfordian Reef, Cap Ghir.



Photomicrograph illustrating Sinemurian euhedral dolomites and associated intercrystalline porosity (blue)

Nawwar Al-Sinawi (3rd year PhD) is working on the project **Dolomitization of Jurassic Carbonates in the Western High Atlas of Morocco: processes and implications for reservoir properties**, supervised by Cathy Hollis, Stefan Schröder and Jonathan Redfern.

The research aims to understand the extent and origin of Jurassic carbonates dolomitized platforms across the Central Atlantic margin. These platforms were periodically dolomitized and constitute proven, but poorly understood reservoirs, offshore Morocco. Extensive outcrop, petrographic and geochemical analyses in the Essaouira-Agadir Basin (EAB) was performed to determine the controls on dolomite distribution in the Lower Jurassic (and Upper Jurassic units).

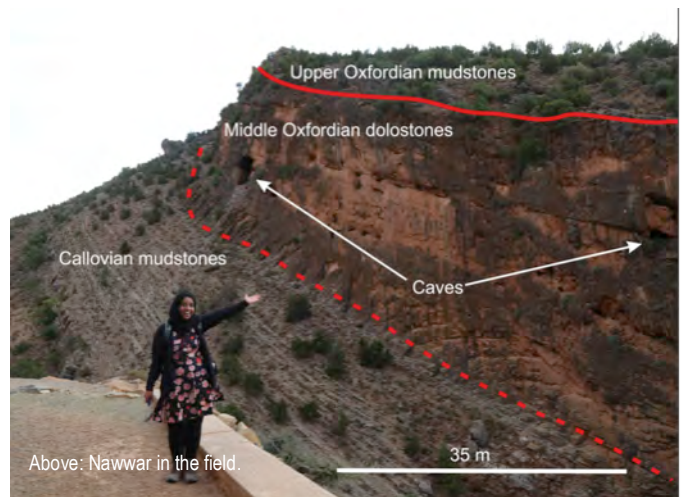
Results from the Lower Jurassic dolomites suggest dolomite formation at two different stages: 1) as a result of seawater reflux (i.e. slightly evaporated seawater), and 2) by interaction with the underlying Triassic salts during salt diapirism. The Upper Oxfordian discontinuous coral build-ups show complex lateral and vertical facies variations forming stratabound and non-stratabound dolostone bodies.

Dolomitization occurs predominantly in coral rich floatstones and rudstones and comprises anhedral and saddle dolomite textures with a dull luminescence under CL. These dolostones illustrate complex porosity and permeability distribution.

Stable isotopes, strontium isotopes and clumped isotopes data suggest Upper Oxfordian dolomite formation by two different fluids (i.e. seawater and hydrothermal fluids). Hydrothermal fluids could have migrated along strike-slip and thrust faults created during the Alpine orogeny. It is possible that the concentration of Mg²⁺ within the fluids was increased by interaction with olivine and pyroxene within the Central Atlantic Magmatic Province (CAMP) basalts.

Core from Jurassic of Nova Scotia, comparable age and facies to that being investigated at outcrop in Morocco.

Examined by Aude and Nawwar following last years Conjugate Margins Conference.



Above: Nawwar in the field.

Biostratigraphy Update



Recent activity:

- December 2018: Visit to Tubingen and Bremen. Study fossil collections from Maio (Casson et al., 2019, in press) and survey of Egyptian collections in collaboration with Jens Lehmann
- February 2019: Visit to Marrakech and Agadir. Preparation, photography and cataloguing of Lower K ammonites collected during October 2018 field trip with PhD Orrin Ryers.
- Collaboration with Profs Moussa Masrouf and Mohssine Ettachfani.
- We have made an agreement that a reference collection should be left in Morocco and deposited in the new Museum of Geology at Agadir University.



MSc Project:

- Meghan Jenkinson** (MEarthSci student at Manchester) since September 2018: The late Aptian adaptive radiation of the Acanthoplitidae in the Essaouira-Agadir Basin of Morocco.
- Main results: 1 new species described.
- Local evolution of the family from a Caucasian- Mediterranean rootstock during the late Aptian evidenced.
- Population dynamics shows three short phase of immigration followed by in situ evolution of the fauna and reflects 3rd order cycles.



New Project: DAFCOAE (Dynamics of ammonoid faunas during Cretaceous oceanic anoxic events)

Leader: Dr. Luc Georges Bulot (Cerege, CNRS, Marseille, France)

External collaborators: Prof. Mohamed Fouad Aly (Cairo University, Egypt) and Prof. Jens Lehmann (University of Bremen, Germany)

Study area: Iran, Egypt, Morocco

- Compared to many other regions of the globe, our knowledge of the Cretaceous ammonoid faunas of North Africa and the Middle East remains at a very preliminary stage. Although the first ammonites were identified as early as the 19th century, most data were acquired during the 20th century. Overall, all these works lack stratigraphic precision, which has resulted in many confusions as to the interpretation of the described faunas, both biostratigraphically and biogeographically.
- The Moroccan fauna collected during the PhD theses of Tim Luber and Jianpeng Wang (NARG) remain to be formally documented (in particular C / T of the Tarfaya basin) but represent a plentiful and easy database to complete under the agreements between Ohnym and NARG.
- The outcrops of the Cretaceous of northern Egypt are currently very difficult to access (impossible for Sinai). Abundant collections, well constrained stratigraphically, were made independently by Prof. Jens Lehmann and Prof. Mohamed Aly. They make it possible to overcome this problem and to use Egyptian fauna as the link between Atlantic Morocco and the Middle East. Systematic analysis of the faunas is in progress (MSc Nard, MSc Univ Cairo, MSc Univ Aswad) with more to follow (subject of MSc Univ Bremen). Tunisian faunas are well known thanks to an abundant bibliography and can be incorporated on the basis of published data.
- In the longer term, the aim of the project is to compare local expressions of faunal dynamics under the influence of palaeogeographic and paleo-oceanographic changes related to the establishment of successive stages of Cretaceous AEOs (Barremian to Turonian).
- Mohamed F. Aly is Professor of Paleontology and Stratigraphy.

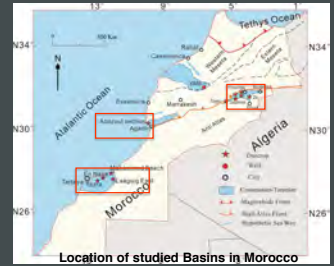
He is currently Head of the Department of Geology at Cairo University.



Recently Completed Studies



Jianpeng Wang completed his PhD thesis and graduated in 2019. He has been working on a regional evaluation of the OAE2 interval, supervised by Prof Jonathan Redfern, Prof Kevin Taylor and Dr Luc Bulot, a project that spans the Cenomanian-Turonian to examine depositional controls on source rock development, comparing the development along the Tethyan and Atlantic margins.



Aude Duval-Arnould graduated in 2019, supervised by Stefan Schröder, Jonathan Redfern and Luc Bulot, working on Jurassic depositional systems and stratal architecture in the Essaouira-Agadir Basin, Morocco. She is continuing with NARG as a PostDoc for the next two years to extend her study, build regional palaeogeography maps and look at controls on clastic input within this carbonate dominated interval



Leonardo Muniz Pichel, working with Mads Huuse, Emma Finch, and Jonathan Redfern, has completed his PhD, which examines the evolution of the Essaouira salt basin. This study expands on previous work in the basin by integrating interpretation of new seismic (2D and 3D) and well data with both numerical and kinematic models to: 1) test earlier concepts, 2) investigate the origin and mechanisms controlling different geometries and kinematics along the margin; 3) analyse the effects of pre-salt topography and regional events on salt deformation; and 4) evaluate the timing and generation of allochthonous salt and their potential effects on paleo-bathymetry.



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

Offshore well and 2D seismic data to evaluate the Moroccan Atlantic margin salt basins has been kindly provided by ONHYM. Kosmos are also gratefully acknowledged for permission to access their 3D data.

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>

Biostratigraphic framework for the Berriasian to early Barremian Essaouira-Agadir Basin

More from MSGBC - Senegal and The Gambia

We have commenced a new outcrop-based study with PhD Orrin Bryers, to build a biostratigraphic framework for the Berriasian to early Barremian intervals in the Essaouira-Agadir Basin using an integration of ammonite, calpionellid, foraminifera and C13/O18 isotope analyses.

Initial Results:

1. Biostratigraphic re-evaluation of the J/K boundary through to Lower Hauterivian has been established in the marine realm of the SW Moroccan Atlantic margin.
2. Identification of a Middle Berriasian Unconformity, which may be part of a global-scale hiatus e.g. Scotian Basin, Cape Verde, North Atlantic
3. A new confined turbidite system has been discovered in the EAB, linking to key sediment influxes towards the distal basin in the Valanginian-Hauterivian interval.
4. Detailed study initiated of the carbonate build-ups.



Max Casson undertook fieldwork in April 2019 with Ian Mouteneay, to collect river samples for the provenance analysis, and then has spent 2 months in Equinor undertaking an internship.



He has his second paper submitted, based on the collection of data from field localities in Senegal and Cap Verde and sampled core and cuttings from exploration wells, which together with re-sampling of IODP material. A provisional biostratigraphic framework is now in-place for the deep basin and we aim to extend this on to the shelf by incorporating data from Senegal.

Latest publications:

Casson, M.A., Cavin, L., Jeremiah, J., Bulot, L., Redfern, J. 2018. Fishing in the Central Atlantic, an earliest Cenomanian ichthyofauna, DSDP 41-367, Cape Verde Basin. *Journal of Vertebrate Palaeontology*

Casson, M.A., Bulot, L., Jeremiah, J., Redfern, J. (2019) Deep sea rock record exhumed on oceanic volcanic islands: Cretaceous sediments of Maio, Cape Verde. *Gondwana Research* (accepted).

Casson, M.A., Calvès, G., Redfern, J., Huuse, M., Sayers, B. (2019) Cretaceous submarine canyon inception, slope processes and seascape evolution from quantitative seismic geomorphology offshore NW Africa. *Basin Research* (to be submitted).

NARG Morocco Workshops and Field Courses



- NARG runs a number of field courses and workshops. annually as part of the consortium.
- These have been well-attended and this year the field trip will be to Eastern Morocco, to examine the Palaeozoic Petroleum Systems, and look at key components of the new Triassic tight gas play, related to the Sound Energy Tendrara discovery.
- We also run a trip to the west coast of Morocco to examine the Atlantic Margin play.

Atlantic Margins Petroleum Systems

This 7-day field workshop examines the evolution of the Atlantic margin, from the Hercynian basement, Triassic syn-rift and into the Jurassic and Cretaceous passive margin fill. Superbly exposed in the High Atlas and Essaouira-Agadir Basins, areas where we have undertaken extensive research.

Aim: Evaluate the tectono-stratigraphic framework, reservoir characterization, source rocks and depositional systems. Analogue to plays in the Central Atlantic, Morocco, MSGBC Basin and Nova Scotia, Eastern USA.



Eastern Morocco Palaeozoic Petroleum Systems

A 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

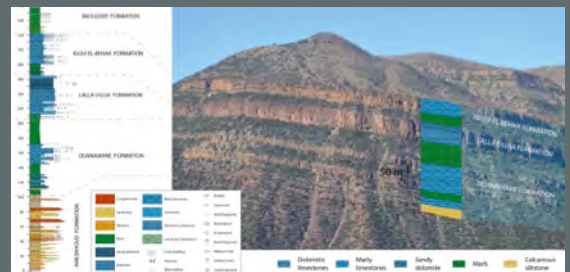


Tailored Field Courses

Looking for something more bespoke? NARG Consultancy can provide field courses tailored to meet company requirements.

These can focus on clastic or carbonate depositional systems, source to sink or key aspects of the regional geology.

Morocco offers exceptional exposures, great infrastructure and hotels and an unsurpassed welcome. We have decades of experience of running trips (over 20), many tailored to companies requirements.



Recent Publications and Upcoming Conference Presentations

Luber, T., Bulot L.G., Redfern J, Nahim, M., Jeremiah, J., Simmons, M., Bodin, S., Frau, C., Bidgood, M., Masrour, M., 2019. A revised chronostratigraphic framework for the Aptian of the Essaouira-Agadir Basin, a candidate type section for the NW African Atlantic Margin. *Cretaceous Research* 93, 292-317. <https://doi.org/10.1016/j.cretres.2018.09.007>

Casson, M.A., Cavin, L., Jeremiah, J., Bulot, L.G., Redfern, J., 2018. Fishing in the Central Atlantic, an earliest Cenomanian ichthyodectiform, DSDP 41-367, Cape Verde Basin. *Journal of Vertebrate paleontology*. Article: e1510415 (5 pages). <https://doi.org/10.1080/02724634.2018.1510415>

Bulot, L.G., Frau, C., Pictet, A., 2018. Revision of *Toxoceratoides royeri* (d'Orbigny, 1842) and its bearing on the systematics of the Aptian Acrioceratidae Vermeulen, 2004 (Ammonoidea, Ancyloceratina, Ancyloceratoidea). *Cretaceous Research* 88, 187-196. <http://dx.doi.org/10.1016/j.cretres.2017.03.020>

Charton, R., Bertotti, G., Arantegui, A., Bulot, L.G., 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, 22-32. <https://doi.org/10.1016/j.jafrearsci.2018.01.006>

Frau, C., Tendil, A.J.-B., Lanteaume, C., Masse, J.-P., Pictet, A., Bulot, L.G., Luber, T.L., Redfern, J., Borgomano, J.R., Leonide, P., Fournier, F., Massonat, G., 2018. Late Barremian-early Aptian ammonite bioevents from the Urgonian-type series of Provence, southeast France: Regional stratigraphic correlations and implications for dating the peri-Vocontian carbonate platforms. *Cretaceous Research* 90, 222-253. <http://dx.doi.org/10.1016/j.cretres.2018.04.008>

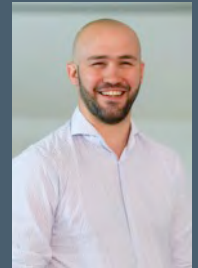
Frau, C., Bulot, L.G., Delanoy, G., Moreno-Bedmar, R, J.A., Masse, J.-P.; Tendil, A.J.-B., Lanteaume, C., 2018. The Aptian GSSP candidate at Gorgo a Cerbara (Central Italy): an alternative interpretation of the bio-, litho- and chemostratigraphic markers. *Newsletters on Stratigraphy* 51/3, 311-326. <http://dx.doi.org/10.1127/nos/2017/0422>

PESGB Africa Conference

Come and visit us at Booth C6. We have a range of talks and posters during the 2-Day Conference.

New Post Doc takes us back to Tunisia

We welcome Pierre-Olivier Bruna as a new Post Doc working with NARG at TuDelft.



He is a structural geologist, who obtained his PhD in geology in 2013 in Aix-Marseille University (France). In late 2013, he was recruited by the Northern Territory Geological Survey (Australia) to investigate the hydrocarbon potential of the greater McArthur Basin. In 2016, he joined the CEG group of TU Delft, to develop new methods of prediction of the geometry and of the properties of subsurface fracture networks in various tectonic contexts.

These methods were calibrated using multiscale characterisation (from ground work to aerial imagery) of carbonate and siliciclastics outcrops analogues (Croatia, France, Brazil, Australia).

In late 2018, a collaboration was initiated between TU Delft and Mazarine Energy B.V. – an O&G company operating in Tunisia – and a regional structural geology study of the Southern Chotts Basin was undertaken.

In Mid-2019, Mazarine joined the NARG consortium and sponsored part of my post doc research for the coming three years. The project is focused on the characterisation of Triassic tectono-sedimentary systems of Central Tunisia and its adjacent regions.

This project aims to better understand the deformation associated with the Hercynian orogeny that deeply affected the architecture and the properties of major regional Paleozoic naturally fractured reservoirs (NFR).

This project will also focus on the characterisation of fracture networks in outcrops (using classical field work methods, drone imagery, automatic fracture detection tools) and the prediction of the fracture network geometry and efficiency at depth (using DFN models, extrapolation techniques such as multiple point statistics algorithms and advanced deep learning methods).



Special Session on Petroleum Systems in North Africa by North Africa Research Group (NARG) of Manchester University

Oral presentations. Special Session on Petroleum Systems in North Africa by North Africa Research Group (NARG)

North Africa Petroleum Systems.

26 November 2019
11:00 - 12:30

The North Africa Research Group (NARG) was founded in 2000 at the University of Manchester, UK. NARG brings together industry, academia and other local stakeholders with the desire to promote multi-disciplinary research with a petroleum geoscience theme across northern Africa.

Four plenary speeches (3 confirmed) are planned during this special session by:



Jonathan Redfern
Guest of Editorial Board
Arabian Journal of Geosciences
Chair of Petroleum Geoscience
University of Manchester, UK



Giovanni Bertotti
Guest of Editorial Board
Arabian Journal of Geosciences
Geoscience & Engineering, Delft University
of Technology, The Netherlands

Bulot, L.G., Redfern, J., Luber, T., Simmons, M., Jeremiah, J. 2019. Back to the field: the limits of standard scales in High Resolution stratigraphy. Examples from North West Africa and the Middle East.

Lovell-Kennedy, J., Redfern, J., Argent, J., and Caning, J. Evolution of Upper Triassic Fluvial Systems across North West Africa; the interplay of local versus regional drainage systems.

Bertotti, G., Charton, R., Gouiza, M., Roquette E., Lovell-Kennedy, J and Redfern, J. Vertical Movements and source-to-sink systems in the rifted margin of NW Africa: surprises continue

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We thank the continued support of staff in Onhym, both technical (Mr Nahim, Mr Jabour and Mr Ait Salem, and in the field, with Mohamed Taki, Yousfi Zakaria, Lahsen Aabi, Walid Kassoui

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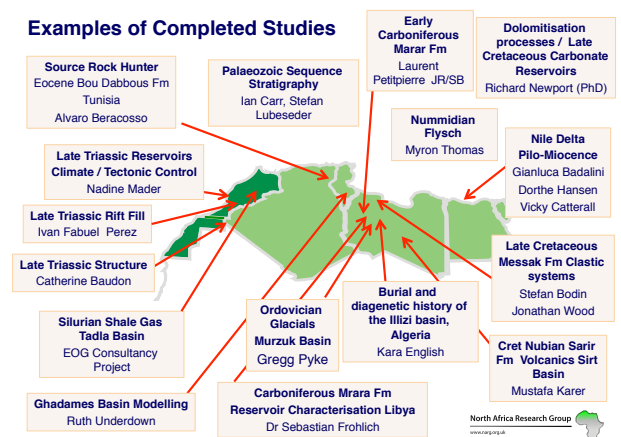
PostDoc:
Dr Remi Charton
Dr Pierre-Olivier Bruna

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Research Associates / Collaborations:

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Examples of Completed Studies



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