



CARBONATE FORUM 2020

CONFERENCE
WORKSHOP

12-14 MAY
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FOREWORD

This meeting was initiated in summer 2019 after discussions amongst members of the scientific committee about the importance conference participation had played in our early scientific careers. In particular, many of us cut our teeth at British Sedimentological Research Group and Bathurst Meetings, presenting to sedimentologists whose experience ranged from a few years to decades. The format of the meetings was strict – talks were short, time-keeping was essential, and the scientific content of the talks didn't need to be 'polished'. It was more important that you communicated the hypothesis and scientific principles of your study, and the concepts behind the work, then focus on the final results and their application. In essence, fundamental science was critical, even if ideas and results were not fully formed. Questions and feedback was as important as the presentation – talks and posters were there to initiate discussion, forcing the presenter and the audience to think about the implications of the presentation.

Although there are now endless opportunities for scientists of all ages, experience and nationality to participate in conferences, there is often more of an expectation – real or perceived – that data will be conclusive, ideas established, and results applicable to industrial end-users. The number of conferences has increased, along with the size of individual meetings, and discussion time is often cut short. PhD students can feel inhibited from presenting in the early years of their research, at a time when they could most do with positive feedback and ideas from outside their immediate sphere of influence. It is can also be difficult for early career researchers to obtain an oral presentation slot; those who do succeed can feel obliged to present the results they are most confident of, rather than more provocative – but potentially far-reaching – ideas.

With these motivations, we decided to make this a conference just for young researchers with the hope that experienced carbonate sedimentologists would come to listen to them and provide useful, constructive feedback. We also wanted to ensure that the scientific content embraced the diversity of modern carbonate research – not just sedimentology and diagenesis, but also geobiology, geochemistry, modern carbonates, the study of past global environmental change and numerical modelling. We are thrilled at the response to this conference, which suggests there really is demand for this kind of meeting. In addition, the sudden change in world events that moved this from a physical to a virtual conference, although tragic in most respects, has had the unanticipated consequence of increasing demand to join this conference– interest in the conference is greater, and participation more international as a result of the lockdown in response to Covid-19.

Pulling all this together on such shifting sands has been challenging, but greatly facilitated by the support of SedsOnline, and the International Association of Sedimentologists, who we would like to thank profusely for their support. We would also like to thank Prof Martin Blunt and Dr Ashleigh Hood for accepting our invitation to be keynote speakers at short notice, and Schlumberger® for offering a short course on Day 3, in replacement of the planned field trip. As we potentially enter a very different world, it remains to be seen if the next Carbonate Forum is real or virtual, but we very much hope that this is the start of a tradition for young researchers that offers us much to them as it did to us.

Cathy Hollis, Peter Burgess, Stephen Lokier, Stefan Schroder, Fiona Whitaker, Rachel Wood

Carbonate Forum, Scientific Committee

SCIENTIFIC COMMITTEE



Prof. Cathy Hollis

University of Manchester



Dr. Stephen Lokier

Bangor University



Prof. Rachel Wood

University of Edinburgh



Prof. Fiona Whitaker

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Prof. Pete Burgess

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Prof. Cathy Hollis

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Connor Doyle



Dr. Stephen Lokier

Bangor University



Dr. Catherine Russell

University of Leicester



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PROGRAMME OVERVIEW

	Tues 12th May	Wed 13th May	Thurs 14th May
9am	Sedimentological evaluation of carbonate platforms	Keynote, Dr Ashleigh Hood, University of Melbourne, Australia	Schlumberger Petrel GPM workshop (separate registration needed)
10am		Past climates	
11am	Sedimentological processes		
12pm		Breakout discussions, posters	
1pm	Microbial and non-marine carbonates		
2pm		Marine and near surface diagenesis	
3pm			
4pm	Break	Burial Diagenesis	
	Keynote: Prof Martin Blunt, Imperial College, London		
5pm			

DETAILED PROGRAMME

DAY 1 TUESDAY 12th MAY 2020

** presenting author. Affiliation shown for lead (presenting) author only*

8.50 Introduction and Welcome: Cathy Hollis

Session 1 Sedimentological evaluation of carbonate platforms

Chair: Peter Burgess

9.00 Morphology and Depositional Architecture of a Miocene Carbonate Platform, Central Luconia: An Insight from wave pattern analysis

Muhammad Hanif Haziq*, D.A. Uli, Dr. Z. Z. T. Harith, M.M.H. Mohammad, G. Primadani, A. Kolupaev, S.Fun, Z.Mohammad, G. Primadani & J. Margotta

Beicip-Franlab, Asia

9.20 Sedimentary evolution and vertical movements of Cenomanian to Santonian carbonate platforms in Iberia

Nicolas Saspiturry*, Simon Andrieu, Marine Lartigau, Benoit Issautier, Paul Angran, Eric Lasseur and Tiago M. Alves

Université Bordeaux Montaigne, France / University of Cardiff, UK

9.40 Seismic-scale coral carpets on a mixed carbonate-siliciclastic shelf; a sedimentological study from the Lower Cretaceous of NW Africa

Orrin Bryers*, Jonathan Redfern, Luc Bulot & Aude Duval-Arnould

University of Manchester, UK

10.00 Geometric changes of carbonate platforms through the Miocene and implication to changes in modes of production; Eratosthenes Seamount, Eastern Mediterranean

Or Bialik*, Thomas Lüdmann, Yizhaq Makovsky, Giovanni Coletti, Aaron Meilijson, Nicolas Waldmann, Axel Ehrhardt, Christian Hübscher, Christian Betzler

University of Hamburg, Germany / University of Haifa, Israel

10.20 A 3D Outcrop and Laboratory Study of a Jurassic Carbonate Ramp: the Hanifa Formation, Central of Saudi Arabia

Ahmad Tayeb*, John Howell, Alexander Brasier, Mohammed Khalil

University of Aberdeen, UK

10.40 **BREAK**

Session 2 Sedimentological processes

Chair: Stephen Lokier

11.00 Lateral sedimentological variability of calcareous tempestites

Thomas Haines*, Joyce Neilson

Independent / University of Aberdeen, UK

11.20 Sedimentological study of Miocene coral carbonate facies in the Syracuse area (Sicily)

Claudia Morabito*

University of Ferrara, Italy

- 11.40 Spatial self-organization and autogenic dynamics of peritidal carbonate system: insights from stratigraphic forward modelling
Haiwei Xi* and Peter Burgess
University of Liverpool, UK
- 12.00 Tracing the origins of marine epiphytic environments: new insights from Upper Triassic shallow water carbonates of the Yukon, Canada
Nicolo del Piero*, Sylvain Regaud, Rossana Martini
University of Geneva, Switzerland
- 12.20 Sensitivity Analysis of the Amplitude of Early Cretaceous Short-Term Eustatic Changes Using Forward Stratigraphic Modelling (Resolution Guyot, Mid-Pacific Mountains)
Mahmoud El Yamani*, Cedric M. John, and Rebecca E. Bell
Imperial College, University of London, UK
- 12.40 LUNCH, POSTERS AND BREAK OUT DISCUSSIONS**
- Session 3 Microbial and non-marine carbonates**
Chair: Rachel Wood
- 13.30 Analysing statistical properties and heterogeneity of Holocene freshwater dolomites from Hungary using CT data
Nour Alzoubi*, Sandor Gulyas, Janos Geiger
University of Szeged, Hungary
- 13.50 Microbial versus abiotic controls on Mg- and Ca-carbonate precipitation and diagenesis: Insights from a modern hydromagnesite-magnesite playa, Atlin, BC, Canada
Tom Kibblewhite* Emily Junkins, Fiona Whitaker, and Bradley Stevenson
University of Bristol, UK
- 14.10 Deposition of the pre-Salt microbialite in the Kwanza Basin, Angola
Nathan Rochelle-Bates*, Stefan Schroeder, Richard Dixon
University of Manchester, UK
- 14.30 Depositional environment and diagenesis in the Barra Velha Formation deposits at Brazilian pre-salt: new insights from carbon and oxygen isotope analyses
JP Gomes*, A.C.L. Sartorato, L.R. Tedeschi, S.N. Tonietto, M.E. Tucker, F.F. Whitaker
University of Bristol, UK / Petrobras Brazil
- 14.50 Petrological, geochemical and morphological characteristics of modern and ancient lacustrine microbial carbonates of the Iberian Peninsula
Connor Doyle* Stefan Schröder, Juan Pablo Corella, Blas Valero Garces, Julia Behnsen
University of Manchester, UK
- 15.10 BREAK**

- 16.00** **Keynote:** Flow in porous materials: a tale of X-rays, minimal surfaces and wettability
Martin Blunt, Imperial College London, UK
- 17.00** **SOCIAL AND GENERAL DISCUSSION**
- 18.00** **CLOSE**

DAY 2 WEDNESDAY 13th MAY 2020

** presenting author. Affiliation shown for lead (presenting) author only*

- 9.00** **Keynote:** The chemical history of seawater: insights from marine carbonates
Ashleigh Hood, University of Melbourne, Australia
- Session 4** **Past Climates**
Chair: Rachel Wood
- 10.00** The control of PO₄ on Neoproterozoic marine carbonates
Sacha Roest-Ellis*, R. Pietzsch, O. Gaitonde, J. Strauss, J. Richardson, S. Webb B. Phillips & N. Tosca
University of Oxford, UK
- 10.20** A Cretaceous alkaline lake as an analogue for the prebiotic P-cycle?
Raphael Pietzsch*, Sascha Roest-Ellis, Nicholas J. Tosca
University of Oxford, UK
- 10.40** Dating records of past seafloor methane emissions along the US Atlantic margin
Diana Sahy*
British Geological Survey, UK
- 11.00** The Middle Eocene Climatic Optimum in the Hampshire Basin: new insight from carbonate clumped-isotope thermometer
Marta Marchegiano* and Cedric John
Imperial College, University of London, UK
- 11.20** Dating carbonates with in situ U-Pb geochronology (POSTER)
Nick Roberts
British Geological Survey, UK
- 11.25** **BREAK**
- Session 5** **Platform scale and fault controlled fluid flow**
Chair: Fiona Whitaker
- 11.40** A method for constraining fluid advection rates on carbonate platforms using calcium and clumped isotopes
Philip Staudigel*
University of Cardiff, UK

- 12.00 Controls on the Localisation of Fault/Fracture Controlled Dolomitization: insights from the Derbyshire Platform, Lower Carboniferous, UK
Catherine Breislin*, Cathy Hollis, Ian Millar, Vanessa Banks, James Riding
University of Manchester, UK
- 12.20 High temperature fault-controlled dolomitization by convection of seawater: concept evaluation using reactive transport modelling
Rungroj Benjakul*, Cathy Hollis, Hamish A. Robertson, Eric L. Sonnenthal, Fiona Whitaker
University of Bristol, UK
- 12.40 Reconstructing fluid circulation pathways in volcanically influenced settings: a case study from the Namibe Basin (Angola) (POSTER)
Edoardo Fiordalisi, Gustavo do Couto Pereira, Nathan Rochelle-Bates Nathan, Marta Marchegian, Cedric John, Richard Dixon, Ian Sharp, Stefan Schröder
University of Manchester, UK
- 12.45 LUNCH, POSTERS AND BREAK OUT DISCUSSIONS**
- Session 6 Marine and near surface diagenesis**
Chair: Stefan Schroeder
- 13.30 Biogeochemical drivers of modern carbonate firm-ground formation: Yas lagoon, Abu Dhabi
Hazel Vallack*, Sarah E. Greene, Stephen W. Lokier, Jens Holtvoeth, Victoria A. Petryshyn, Emily N. Junkins, Bradley S. Stevenson, Fiona Whitaker
University of Bristol, UK
- 13.50 Karst Geobody Extraction through the combination of Karst Characterisation Workflow and Principal Component Analysis (PCA) in Carbonate Fields of Central Luconia Province, Sarawak
Sook Fun Lim*, D.A. Uli, A. Kumar, M.H.H. Mohammad, Z. Mohammad, Z.Z. Tuan Harith, A. Kolupaev and Y.F. Zainudain
Beicip-Franlab, Asia
- 14.10 Differential diagenesis caught in the act: lithological dependence of Hydrobia (gastropod) preservation in monospecific deposits from the Miocene Mainz Basin (SW Germany)
Theresa Nohl*, Jannick Wetterich, Axel Munnecke
Friedrich-Alexander-Universität, Germany
- 14.30 Influence of long term exposure surfaces on the compartmentalization and distribution of microporosity in shallow water carbonates
Hugues Biltault*, Philippe Leonide, François Fournier, Cathy Hollis, Matthieu Rousseau & Jérôme Hennuy
University of Manchester, UK

14.50 Petrophysical and Acoustic Properties of Two Middle East Reservoirs; A Comparison between Calcitic and Aragonitic Sea Deposits

Moaz Salih*, John J.G. Reijmer, Luis A. González, and Ammar El-Husseiny

KFUPM, Saudi Arabia

15.10 **BREAK**

Session 7 Burial diagenesis

Chair: Cathy Hollis

15.30 Hot and late: clumped isotopes in Middle Jurassic calcite-cemented concretions from Skye

Richmal Paxton*, Julian Andrews, Paul Dennis, Alina Marca

University of East Anglia, UK

15.50 Hydrobreccias, Zebra Dolomite, and Crack-Seal Textures; Implications for the Emplacement of Fault-Controlled Dolomite

Cole McCormick*, Cathy Hollis, Ernie Rutter, Hilary Corlett

University of Manchester, UK

16.10 The impact of hydrocarbon emplacement on cementation in carbonate reservoirs

Stephen Gundu*, Cess van der Land, Sanem Acikilan, Tannaz Pak, Shannon Flynn, Laura Galluccio

Newcastle University, UK

16.30 Diagenetic evolution of Jurassic platform carbonates along the NE Atlantic Margin

Nawwar Al Sinawi*, Cathy Hollis, Stefan Schröder, Jonathan Redfern

University of Manchester, UK

16.50 Application of Clumped Isotope Palaeothermometry to reconstruct thermal evolution of recrystallised calcite in fine-grained micrites

Sarah Robinson*, Cédric M. John, Annabel Dale, Mark Osborne

Imperial College, University of London, UK

17.10 SOCIAL AND GENERAL DISCUSSION

18.00 CLOSE

DAY 3

9am – 1 pm Schlumberger Petrel GPM workshop (separate registration needed)

ABSTRACTS

Flow in porous materials: a tale of X-rays, minimal surfaces and wettability

Prof Martin Blunt, Imperial College, London, UK

I will provide an overview of the current revolution in our understanding of flow, transport and reaction processes in porous media, enabled by 3D imaging from the nanometer scale upwards, micro-fluidics, and improved numerical methods. This will be illustrated by examples from work at Imperial College London on multiphase flow in rocks with application to carbon dioxide storage and oil recovery. X-rays are used to image flow processes in rocks at a spatial resolution of down to 1 micron and a time resolution between 1 and 1,000 s. These experiments can be used to measure traditional multiphase flow properties – relative permeability and capillary pressure – while providing pore-scale insight into displacement processes. We show how an accurate characterization of wettability, or the local distribution of contact angle, enables us to understand flow and trapping, and explain the circumstances which are optimal for storage or recovery applications. The experiments also provide a wealth of data to calibrate and validate pore-to-core scale flow and transport models.

The chemical history of seawater: insights from marine carbonates

Dr Ashleigh Hood, University of Melbourne, Australia

The chemical composition and redox state of seawater is intimately linked to Earth's crustal evolution, climate history and changing biosphere, all of which have evolved considerably through Earth's history. Lawrence Hardie in his 1996 paper (*Geology*, 24, p. 279-283) observed that “the major ion chemistry of seawater has changed significantly back through geologic time. This point of agreement transcends the existing disagreements on the details of the changes and should provide us with an important stimulus to expand our efforts to unravel the apparently eventful chemical history of seawater”. Over the last several decades, there have been considerable advances in our understanding of this eventful chemical history of seawater, particularly in relation to major element composition, redox conditions and nutrient availability; all the way from the early Archean to today. Many of these advances have been insights from the sedimentology and geochemistry of carbonates. In this overview I will present a broad chemical history of seawater, with an emphasis on new and published data from marine carbonates. In particular, I will focus on the links between carbonate mineralogy and the major ion composition of seawater; ocean redox conditions and the Precambrian "dolomite problem" ; and how a low-oxygen Precambrian ocean-atmosphere may have significantly influenced the style and chemistry of Earth's early carbonate systems. In many aspects of this ocean history, it appears that the present may not always be the key to the past.

1 MORPHOLOGY AND DEPOSITIONAL ARCHITECTURE OF A MIOCENE CARBONATE PLATFORM, CENTRAL LUCONIA: AN INSIGHT FROM WAVE PATTERN ANALYSIS

D.A. Uli, Dr. Z. Z. T. Harith, M.M.H. Mohammad, G. Primadani, A. Kolupaev, S.Fun, Z.Mohammad, G. Primadani & J. Margotta

PETRONAS Carigali Sdn Bhd, Beicip Franlab Asia

Miocene carbonates platform in Central Luconia has been extensively studied for more than 25 years (Fathiyah et al., 2017). However, the relationship and impacts of waves and bottom current to the growth of carbonates build-ups have not been revealed sufficiently.

In this work, seismic and well log data from carbonate fields were analysed in a sequence stratigraphy context. Analysis of data showed good agreement between the stratigraphic record and global sea level curves, clearly indicating that eustasy was the main controlling factor in carbonate platform development. However, a parameter usually overlooked are the influence of waves and bottom currents which plays a crucial role at times and responsible for considerable facies variations.

A study was done in a platform in Central Luconia. Stratigraphically, the platform consisted of a bigger carbonate platform (megaplatform) with later, two smaller platforms (microplatform) forming during subsequent back-stepping after a long-lived subaerial exposure event. The interpreted windward margin for the megaplatform was its north portion while the microplatform has an eastern windward margin interpretation. According to the Miocene wave pattern interpretation (Vahrenkamp, 1998), there was no change in the major winter wave monsoon direction during Miocene having greater influence from the north thus it was perplexing on why the windward margin of the shallower microplatforms changed in direction.

Having a regional understanding of the area, during a second-order sea level drop most of the carbonates within the platform vicinity were exposed and seismic evidences of karstic features were seen in the carbonates. Together with the sea level lowering, an influx of clastic sedimentation came into the area. The bathymetry surrounding the carbonate platforms are now shallower from middle bathyal to upper bathyal conditions. The shallower surrounding bathymetry probably created a stronger net refraction energy towards the carbonates as waves passed from north to south (Figure 1). Another observation is how the antecedent topography before the microplatform growth is affected by karst features during eustatic lowstand events resulting in differential carbonate growth in towards the south-eastern part of the megaplatform than the northwest section. Thus, a greater influence of wave energy coming from southeast was felt during the microplatform growth. This concept could be taken further by testing different numerical modeling methods (forward stratigraphic modelling/wave propagation modelling) which utilizes physical laws to recreate geological processes that affects the carbonates.

References

- Jamaludin, S. N., Pubellier, M., & Menier, D. (2017). Structural Restoration of Carbonate Platform in the Southern Part of Central Luconia, Malaysia. *Journal of Earth Science*.
- Vahrenkamp, V. C. (1998). Miocene carbonates of the Luconia province, offshore Sarawak. *GSM Petroleum Geology Conference '97* (pp. 1-13). Geol. Soc. Malaysia.

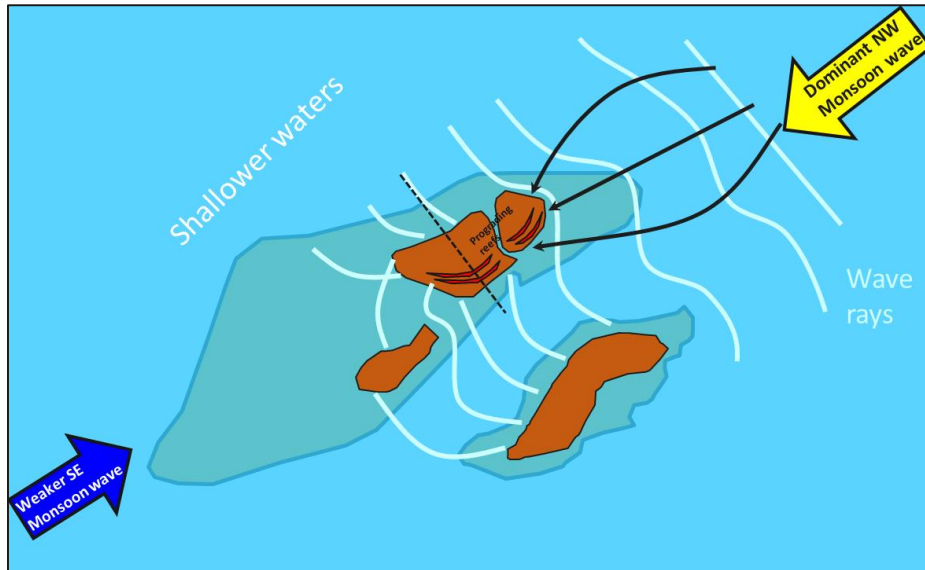


Figure 1: Interpretation of wave propagation during field microplatform growth

2 - SEDIMENTARY EVOLUTION AND VERTICAL MOVEMENTS OF CENOMANIAN TO SANTONIAN CARBONATE PLATFORMS IN IBERIA

Nicolas Saspiturry^{a,b}, Simon Andrieu^c, Marine Lartigau^a, Benoit Issautier^c, Paul Angrand^d, Eric Lasseur^c and Tiago M. Alves^b

^a *Université Bordeaux Montaigne / EA 4592 Géoressources & Environnement, 1 Allée Fernand Daguin, 33607, Pessac Cedex, France*

^b *3D Seismic Lab, School of Earth and Ocean Sciences, Main Building – Park Place, Cardiff CF10 3AT, United Kingdom*

^c *BRGM, 3 avenue Claude Guillemin, BP 36009, 45060 Orléans, France*

^d *Géosciences Environnement Toulouse - Observatoire Midi-Pyrénées*

The Turonian-Early Santonian interval is usually considered as a tectonic quiescent stage around the northern margins of Iberia that preceded the onset of the Pyrenean convergence in the Late Santonian. However, the plate kinematic models explaining the evolution of Iberia during the Mesozoic have serious limitations when estimating the Turonian-Santonian position of Iberia relative to Eurasia. Subsequently, the putative effect of early Pyrenean tectonics has been the subject of increasing debate.

The objective of this work is to reconstruct changes in facies and architecture on carbonate platforms of Iberia and to compare our results at a broad scale so that we improve our understanding of the Iberian-Eurasia geodynamic evolution during the Late Cretaceous. In the Pyrenees, seventeen (17) outcrop sections were studied and twenty-four (24) sedimentary facies identified as representing five depositional environments ranging from the basin floor to backshore. Based on our field data, platform evolution was reconstructed along a west-east cross-section that is nearly 400 km-long. Eleven short-term depositional sequences and five long-term systems tracts were identified on the entire Cenomanian-Santonian Iberian margin platform, around the Pyrenees. Decompacted sedimentation and accommodation rates were computed for eight key localities. A synthesis of the Cenomanian to Santonian sedimentation patterns in the Iberian and Aquitaine platforms, as well in the essentially turbiditic basin, were completed.

In the Cenomanian-Turonian, the Aquitaine and Iberian margins record gentle subsidence, together with the main basin depocentre, as shown by the accommodation rate estimates of 10 to 90 m/My for the margins and ~150m/My for the basin depocentre. Conversely, three domains were differentiated during the Coniacian: (1) the uplifting Iberian margin to the south characterised by negative accommodation rates, karstified surfaces and palaeosoils (~-20m/My); (2) the highly subsiding central domain corresponding to the basin and its borders, with an accommodation rate 2.5 times greater than during the Turonian; (3) the slowly subsiding northern Aquitaine platform (~40m/My). In West Iberia, an abrupt episode of exhumation and regional shift in drainage patterns is recorded in the Lusitanian Basin after the early Turonian. Drainage systems that fed sediment to the south until the Cenomanian changed to a northerly direction after this latter stage.

Following the Turonian, major changes in accommodation and subsidence occur along the Pyrenean domain. Indeed, during the Coniacian, the southern part of the Iberian platform is uplifted while an intense increase of subsidence occurs northward in the turbiditic basin while during the Santonian, subsidence rates highly increase over all the Pyrenean domain. Kinematic models propose a beginning of the convergence between Iberia and Europe during the latest Santonian, but major uncertainties remain on the precise timing of this event, especially because of the small number of sites and samples for the Iberian plate during the Late Cretaceous. We propose that onset of Europe/Iberia convergence within Coniacian time explain the large-scale deformation recorded on the Pyrenean and West Iberian

domains after the Turonian. This interpretation questions the validity of the available plate kinematic reconstructions during the Late Cretaceous and how the compressional strain is distributed through the Iberian plate during this early orogenic stage.

3 - SEISMIC-SCALE CORAL CARPETS ON A MIXED CARBONATE-SILICICLASTIC SHELF; A SEDIMENTOLOGICAL STUDY FROM THE LOWER CRETACEOUS OF NW AFRICA

Orrin Bryers, Jonathan Redfern, Luc Bulot & Aude Duval-Arnould

University of Manchester

Coral-rich successions that form laterally extensive bodies on a shallow marine shelf with little to no internal zonation, known as coral carpets (after Reiss & Hottinger., 1984), are remarkably rare on a regional (10's of kilometre) scale in both modern and ancient marine systems. The onshore Moroccan Atlantic Margin provides a unique opportunity to study a well-exposed, widespread scleractinian coral system which reaches up to 50m thickness in the relatively undeformed, Hauterivian-aged, Tamaran Formation.

Using an integration of modern high-resolution sedimentology and sequence stratigraphy, the geometry and internal architecture/facies variations have been investigated in a mixed carbonate-siliciclastic setting and an interpretation produced of the main controlling factors on coral development and demise.

A stratigraphic framework has been created by defining major sequence boundaries, transgressive and maximum flooding surfaces and establishing depositional sequences. The following depositional evolution has been identified; 1) A regression (shallowing) during which a pioneer stage of low-diversity patchy coral growth occurs preferentially in muddier settings, 2) The disappearance of initial coral networks temporarily during a relatively short transgression (deepening). 3) A second stage of pervasive growth that is associated with a return to a shallow-water, bioclast and nutrient-rich environment that dominates the shelf during a more prolonged regression. 4) A second period of non-deposition, marked by a transgressive hardground surface and coral growth plateaus. 5) The final termination of coral growth as a result of a drop in relative sea level, linked with hinterland uplift, which brings a substantial volume of clastic sediment onto the shelf, associated with higher-energy conditions that erode and subsequently bury the corals carpet. 6) Finally, a major transgression results in the deepening and deposition of progressively thickening marls and limestones which flood the wide shelf.

The coral-bed geometries are mapped as complex bodies, on both a local (10's of metres) and regional (10's of kilometres) scale; log correlations illuminate abrupt thickness variations and facies changes in both strike and dip directions. The study shows that the shelf was perhaps less morphologically uniform than previously understood. Facies variations are hypothesised to be linked with a combination of subtle palaeotopographic disparities associated with the inherited tilted fault block structure and local autogenic controls such as environmental and hydrodynamic regime variations.

This outcrop-based study provides new insights into these uncommon laterally extensive coral carpets that do not display facies zonations typical of large reefal build-ups (Tucker and Wright., 1980). The improved academic understanding of the coral sequences will also help predict and constrain their position along the offshore Moroccan Atlantic margin, offering a potential reservoir target in a challenging basin that requires new and innovative exploration plays.

References:

- Reiss Z & Hottinger L (1984). *The Gulf of Aqaba. Ecological Micropaleontology*. Springer Berlin 352 pp
- Tucker, M & Wright, P.V (1980). *Carbonate Sedimentology*. Blackwell Science.

4- GEOMETRIC CHANGES OF CARBONATE PLATFORMS THROUGH THE MIOCENE AND IMPLICATION TO CHANGES IN MODES OF PRODUCTION; ERATOSTHENES SEAMOUNT, EASTERN MEDITERRANEAN

Bialik, Or M.^{1,2}; Lüdmann, Thomas¹; Makovsky, Yizhaq²; Coletti, Giovanni³; Meilijson, Aaron^{2,4}; Waldmann, Nicolas D.²; Ehrhardt, Axel⁵; Hübscher, Christian¹; Betzler, Christian¹*

¹ University of Hamburg, Germany ²University of Haifa, Israel. ³ Milano-Bicocca University, Italy ⁴ University of Colorado Boulder, USA. ⁵ Bundesanstalt für Geowissenschaften und Rohstoffe, Germany.

The accumulation and bioconstruction patterns of shallow-water calcifying organisms in the Mediterranean realm have changed dramatically from Tethyan times to the modern. Much of the transition in the biogeography of marine carbonate accumulation in this region occurred through the Miocene with the decoupling of the Mediterranean from the world's oceans. Unfortunately, there are very few sites where the entire succession across the Miocene can be observed in shallow water facies. Due to this much of the narrative had to be reconstructed from quilt work of records at different sites, at different latitudes, and across different basins of the Mediterranean. The Eratosthenes Seamount (ESM) is one of these rare sites where a combination of scientific and industrial 2D seismic lines offers a unique opportunity to trace the changes in geometries of shallow-water carbonate accumulations and platforms across the Miocene. Moreover, recent analyses of ODP site 966 core material and new published data from the adjacent Levant basin offer a detailed stratigraphic framework to contextualise these changes.

Detailed analysis of the seismic facies present in the ESM block reveals two marked change in character across the Miocene. The Early Miocene is characterized by a well-developed and large flat-topped carbonate platform that stretches over the entire ESM block. The Middle Miocene sees a decrease in the size of this platform and transition to a grain-dominated production carbonate factory mode marked by large clinoform bodies. This mode continues until the Late Miocene, when carbonate platforms are reestablished, although smaller than their older counterparts.

We suggest that these changes in geometry and production modes of the ESM carbonate factories are a manifestation of the changing oceanographic and climatic conditions of the Mediterranean. While the initial reestablishment of shallow water communities on the ESM was probably driven regional tectonic forcing, the transition to grain dominated environment was driven by the shift to less stable conditions during the termination of connection to the Indian Ocean. Once more stable conditions were established, ridged platforms were able to re-establish but were not as successful in the cooler and more oligotrophic settings.

5 - A 3D OUTCROP AND LABORATORY STUDY OF A JURASSIC CARBONATE RAMP: THE HANIFA FORMATION, CENTRAL OF SAUDI ARABIA

Ahmad Tayeb^{a,b}, John Howell^a, Alexander Brasier^a, Mohammed Khalil^b

^a *University of Aberdeen, School of Geoscience, Geology and Geophysics Department, Scotland, UK*

^b *King AbdulAziz University, Faculty of Earth Science, Department of Petroleum Geology and Sedimentology, Jeddah, Saudi Arabia*

Most of the oil reservoirs in Saudi Arabia exist in carbonate rocks. This study focusses on carbonate outcrops of the Hanifa formation, Late Jurassic (Oxfordian) in the South of Riyadh Region, central Saudi Arabia. The purpose of this project is to understand the high-resolution sequence stratigraphy and determine the depositional environments and diagenesis of Hanifa formation carbonates in this area. In addition, here I will undertake 3D modelling to assess and improve carbonate reservoir characterisation in central Saudi Arabia. Initial fieldwork resulted in production of 4 detailed logs through the Hanifa Formation, together with several virtual outcrops acquired by UAV imaging. The initial working hypothesis is that diagenesis of these carbonate rocks is related to rock characteristics imparted in the original depositional environment. For the first studied section of Wadi Al-Ain we anticipated that most of the beds were deposited in shallow marine water (reef facies) with consequent high carbonate porosity and a relatively high degree of diagenesis. An initial finding is that there is an abundance of coral heads with different sizes and shapes here, and this is consistent with the Wadi Al-Ain sedimentary rocks representing reef facies. However, we find no clear evidence for extensive dolomitization in XRF elemental data obtained so far. Results of fieldwork indicate that the second section in this Wadi seems to overlap between subtidal and intertidal paleoenvironments, and XRF data also show no clear evidence for dolomitization here. A total of 326 samples have so far been collected for petrographic analysis (thin sections, SEM and CL) and geochemistry (XRF for elemental chemistry & stable isotopes of O and C) which will be used to further test the hypothesis. Together with preliminary data acquired in the laboratory, the 3D virtual outcrops enable better understanding of the sequence stratigraphy and Jurassic depositional environments that might be related to hypothesised variable and facies-related diagenesis of the Hanifa Formation.

6 - ALONG-STRIKE SEDIMENTOLOGICAL VARIABILITY OF CALCAREOUS TEMPESTITES

T. J. Haines,^{1,2} and J. E. Neilson¹

¹University of Aberdeen; ²Independent

Modern oceanographic and ancient geological studies suggest that a wide spectrum of hydrodynamic conditions can occur during a storm, ranging from unidirectional geostrophic or density flows to oscillatory flows (Myrow and Southard, 1996). The flow conditions control the degree of erosion and dictate the style of deposition during a storm. Idealised tempestite sequences have been defined based on the recognition of systematic temporal variations in flow conditions during a storm event (e.g. Duke *et al.* 1991). Flow conditions also vary spatially with bathymetry, which has led to the development of a number of proximal to distal tempestite models (e.g. Pérez-López & Pérez-Valera, 2012). Using modern carbonate platform analogues, Harris *et al.* (2015) and Purkis *et al.* (2015) show that texture varies significantly at any subtidal bathymetry, partly due to varying hydrodynamic conditions. Other spatial factors, such as shoreline orientation, storm magnitude and substrate roughness, are also likely to influence the flow conditions during a storm. These factors, coupled with temporal hydrodynamic variability and the non-preservation of storm sediments due to erosion and fair weather bioturbation, suggest that tempestites are heterogeneous. Considering these concepts, we hypothesise that tempestites are represented by facies mosaics in the rock record and thus imply bathymetry-based models do not completely represent the inherent heterogeneity of these deposits.

On the Maltese Islands, ramp-style facies 'belts' strike approximately north-south, with deepening to the east (Brandano *et al.* 2009). North-south-oriented outcrops through thin, calcareous tempestites in the Lower Coralline Limestone Formation, along a c.900m section on Malta, provide an insight into the along-strike variability to test this hypothesis. Sedimentological logs and thin-sections show that these tempestites are mainly composed of grain-supported textures (packstones, grainstones, floatstones and rudstones) with massive, laminated, cross-stratified and bioturbated fabrics characterised by bryozoa and larger benthic foraminifera fragments. Erosive bed contacts are typical, although a well-developed hardground is locally preserved due to variations in erosion. The variation in tempestite fabrics and erosion qualitatively suggest that facies mosaics exist at the outcrop scale. Conversely, increasing bed thicknesses to the north (along depositional strike) coupled with increasing bed abundances and subtle lithofacies trends indicate that more complex along-strike facies patterns exist. This work-in-progress ultimately aims to understand the processes controlling the along-strike facies variability to better quantify the heterogeneity of calcareous tempestites.

References

- Brandano, M., Frezza, V., Tomassetti, L., Pedley, M., & Matteucci, R., 2009, Facies analysis and palaeoenvironmental interpretation of the late Oligocene Attard Member (Lower Coralline Limestone Formation), Malta, *Sedimentology*, **56**, p. 1138-1158.
- Duke, W. L., Arnott, R. W. C. and Cheel, R. J., 1991, Shelf sandstones and hummocky cross-stratification: new insights on a stormy debate. *Geology*, **19**, p. 625-628.
- Harris, P. M., Purkis, S. J., Ellis, J., Swart, P. K. and Reijmer, J. J. G., 2015, Mapping bathymetry and depositional facies on Great Bahama Bank, *Sedimentology*, **62**, p. 566-589.
- Myrow, P. M. and Southard, J. B., 1996, Tempestite deposition, *Journal of Sedimentary Research*, **66**, p. 875-887.
- Pérez-López, A. and Pérez-Valera, F., 2012, Tempestite facies models for the epicontinental Triassic carbonates of the Betic Cordillera (southern Spain), *Sedimentology*, **59**, p. 646-678.
- Purkis, S. J., Rowlands, G. P., and Kerr, J. M., 2015, Unravelling the influence of water depth and wave energy on the facies diversity of shelf carbonates, *Sedimentology*, **62**, p. 541-565.

7 - SEDIMENTOLOGICAL STUDY OF MIOCENE CORALS CARBONATE FACIES IN THE SYRACUSE AREA (SICILY)

C. Morabit

University of Ferrara

This work contains sedimentological and compositional information on the development of Miocene coral colonies in the Mediterranean Sea, global important period for the increase in coral reefs. Stratigraphic sections located in Syracuse in south-eastern Sicily, allowed us to characterize compositional and textural through three sections at Faro Santa Croce, Ognina, Plemmirio, from the upper Tortonian-lower Messinian Monte Carrubba formation, and one at Punta Bonico, from the Burdigalian-Serravallian Calcari di Siracusa member. Our interpretations of these strata were compared with other published models for the Sicilian and Mediterranean area.

The three sections of Monte Carrubba formation are characterized by varying lithofacies, that shows the occurrence of corals in a deep environment. Specifically, the lithofacies CB (corals boundstone), often encrusted by red algae and serpulids, is indicative of a variable depositional depth (mid-inner ramp) for the presence, in some areas, of Nummulitidae, planktonic foraminifera and non-articulated red algae hint a meso-oligophotic zone. The components of the other lithofacies suggests, instead, shallow environments from lagoon, seagrass zone to the possible presence of little oolitic shoals in the carbonate margin. Finally, the small succession of Punta Bonico is composed of three lithofacies: FR (rhodolite floatstone), FC (coral floatstone) and GB (bivalves grainstone). In the first, *Miogypsina* suggests meso-oligophotic environments. The second lithofacies has associations of articulated red algae and *Miliolids* that indicate euphotic zone deposition, although *Miogypsina* and rare planktonic foraminifera indicate a deeper environment. Finally, composition and texture of the last lithofacies indicates high hydrodynamic energy typical of an inner ramp euphotic zone.

The Punta Bonico section doesn't show us satisfying results to locate corals in deeper environment but, comparing the lithofacies with some carbonate ramps from the same age, we had associated them in an inner-mid ramp context. Different speech is for the upper Tortonian-lower Messinian sections, because our findings reveal a spread of coral colonies in deeper habitat while previous authors (Pedley, 2007) put them in euphotic zone. In addition, this could be another confirm of mesophotic coral buildups in a middle ramp zone as was discovered by Morsilli et al, 2012 in the southern Pyrenees, Spain.

The novelty of this study consists in the discovery of deeper coral colonies during the Miocene age, while all previous studies associated them in shallow environment. Even if this study is far from create an exhaustive model, it contains elements that shed new light on the Mediterranean coral successions. In addition, it establishes the basis of future studies with the aim of a detailed investigation of deeper coral colonies, based on a careful observation of the outcrops up to laboratories analysis.

References

Morsilli M., Bosellini F., Pomar L., Hallock P., Aurell M. And Papazzoni C., 2012, Mesophotic coral buildups in a prodelta setting (Late Eocene, southern Pyrenees, Spain): a mixed carbonate–siliciclastic system, *Sedimentology*, **v.59**, p. 766-794.

Pedley M., M. Grasso, R. Maniscalco, and D. Esu, 2007, The Monte Carrubba Formation (Messinian, Sicily) and its correlatives: New light on basin-wide processes controlling sediment and biota distributions during the Palaeomediterranean–Mediterranean transition, *Palaeogeography, Palaeoclimatology, Palaeoecology*, **v. 253**, p. 363–384.

8 - SPATIAL SELF-ORGANIZATION AND AUTOGENIC DYNAMICS OF PERITIDAL CARBONATE SYSTEM: INSIGHTS FROM STRATIGRAPHIC FORWARD MODELLING

Haiwei Xi & Peter M. Burgess

*QUEST Quantitative Experimental Stratigraphy Group, School of Environmental Science, University of
Liverpool, Brownlow Street, Liverpool, L69 3GP, United Kingdom*

**Corresponding author: Haiwei.Xi@liverpool.com*

Spatial self-organization is a process in which coherent pattern emerges through interaction of system components. In depositional systems, it is possible that there is a significant link between self-organization and autogenic dynamics that can create ordered, cyclic strata. Previous modelling work exploring self-organised cyclicity in carbonate strata is explored further here using a different numerical model formulation that is a variant on an existing carbonate forward model CarboCAT. Shoreline and island progradation in the model are comparable to similar effects observed in modern and interpreted in ancient carbonate depositional systems, which generate shallowing-upward cyclical strata. Cyclicity is demonstrated by strong statistical evidence for facies ordering in vertical sections, arising from order in the planform pattern of island progradation. Planform order arises from the self-organising spatial interaction of water-depth-dependent sediment production, transport and deposition processes. The simplest possible model formulation that leads to this self-organised order includes only water-depth-dependent production, straight onshore transport pathway and uniform subsidence. Additional processes such as spatially complex sediment production, local downslope diffusional transport and wave refraction control on sediment transport pathways, lead to diverse island morphologies and variable facies lateral continuities, depending on the actual operations and intensities of these modelled processes. The dominance of long-distance onshore sediment transport over short-distance diffusional transport in our model is essentially a form of activator and inhibitor in Alan Turing's theory to generate ordered patterns, even sometimes the short-distance process is unnecessary. Given the fundamental nature of processes modelled here, it seems likely that similar autogenic, self-organising processes operate in natural carbonate sedimentary system and have had an important influence on the stratigraphic record.

9 - TRACING THE ORIGIN OF MACROPHYTE HABITATS IN NEARSHORE MARINE ENVIRONMENTS: NEW INSIGHTS FROM UPPER TRIASSIC SHALLOW WATER CARBONATES OF THE YUKON, CANADA

Nicolò Del Piero¹, Sylvain Rigaud², Jorge E. Spangenberg³, Marie-Béatrice Forel⁴, Rossana Martini¹

*Nicolò.DelPiero@unige.ch

¹ *University of Geneva, Department of Earth Sciences, Rue des Maraîchers 13, CH-1205 Genève, Switzerland*

² *Asian School of the Environment, 62 Nanyang Drive, 637459 Singapore*

³ *Institute of Earth Surface Dynamics, University of Lausanne, CH-1015 Lausanne, Switzerland*

⁴ *Centre de Recherche en Paléontologie – Paris (CR2P), Muséum national d'Histoire naturelle, 8 rue Buffon, 75005 Paris, France*

Coastal vegetated ecosystems are of primary importance because they form nursery areas and biodiversity hotspots, and since they greatly contribute to carbon sequestration (Macreadie et al., 2019). Tidal marshes, mangroves forests and seagrass meadows contribute to blue carbon storage as important organic producers but also as in these environments high sedimentation rates allow organic matter to enter rapidly into the anaerobic zone, thus escaping remineralization. The presence of marine macrophytes creates a great variety of microhabitats, which are occupied by numerous and conspicuous meadows dwellers; which add to the high in situ organic production. Theoretically, blue carbon environments originated with the adaptation of angiosperms to marine environments (i.e., mangroves and seagrasses) in the Late Cretaceous (Ellison et al., 1999; Reich et al., 2015). Very little is known about similar coastal habitats prior to that time. Here, we present the preliminary results of a study on Upper Triassic organic-rich shallow water carbonate deposits exposed at Lime Peak (Yukon, Canada). These facies, deposited in the inner part of a mud-mound rimmed shelf, were studied using sedimentology, biotic associations (foraminifera and ostracodes), and organic and inorganic geochemistry (Rock-Eval, $\delta^{13}\text{C}_{\text{carb}}$, $\delta^{13}\text{C}_{\text{org}}$ and $\delta^{15}\text{N}_{\text{total}}$ values). Preliminary ostracodes data indicate that shallow-water organic-rich and adjacent biofacies (dominated by ostracodes and heavily calcified green algae) at Lime Peak were deposited in a ramp environment with water depths ranging from medium/deep to very shallow subtidal. Organic and inorganic geochemistry data suggest that organic-rich facies were formed in peculiar environmental conditions, which differ from adjacent biofacies. Organic matter composition varies greatly in this ramp setting: whereas adjacent open-ramp packstones are dominated by terrestrially derived inertinite fragments, organic-rich facies show the dominance of degraded amorphous organic matter. The recurring presence of unattached epiphytic foraminifera, the fine-grained characteristics of the sediment, the presence of carbon enriched holdfast-shaped fenestrae, and the abundant spores of the green alga *Patruluspora pacifica* suggest deposition in a macrophytes-rich environment.

References

- Ellison, A.M., Farnsworth, E.J., Merkt, R.E., 1999. Origins of mangrove ecosystems and the mangrove biodiversity anomaly. *Glob. Ecol. Biogeogr.* 8, 95–115.
- Macreadie, et al., 2019. The future of Blue Carbon science. *Nat. Commun.* 10, 1–13.
<https://doi.org/10.1038/s41467-019-11693-w>
- Reich, S., Di Martino, E., Todd, J.A., Wesselingh, F.P., Renema, W., 2015. Indirect paleo-seagrass indicators (IPsIs): A review. *Earth-Science Rev.* 143, 161–186.

10 - SENSITIVITY ANALYSIS OF THE AMPLITUDE OF EARLY CRETACEOUS SHORT-TERM EUSTATIC CHANGES USING FORWARD STRATIGRAPHIC MODELLING (RESOLUTION GUYOT, MID-PACIFIC MOUNTAINS)

Mahmoud Elyamani¹, Cedric M. John¹, and Rebecca E. Bell¹

¹ Department of Earth Science & Engineering, Imperial College, Prince Consort Road, London, SW7 2BP, UK

Studying eustasy focuses on retrieving global patterns and amplitude of sea level changes from the stratigraphic record. These changes are responsible for patterns in sediment distribution, stratigraphic architecture, facies migration, and durations of submergence and subaerial exposure of deposits. Therefore, studying eustasy is crucial to understand ice-volume changes through time, paleo-climate, and environmental changes along with their impact on diagenesis and petrophysical properties of hydrocarbon reservoirs. Multiple studies focused on eustatic changes during the Cretaceous as an example of greenhouse world. Most of these studies were performed in local areas such as Rohl & Ogg. (1996) in the Pacific Ocean, Sahagian et al. (1996) on the Russian Platform and Siberia, Hardenbol et al. (1998) in Western European basins, and Haq (2014) mainly on the Arabian Plate. These sea level estimates might be derived from localised effects and therefore reflect relative sea level changes rather than eustasy. Based on that, sensitivity analysis to test the applicability of using the Cretaceous eustatic curves of Rohl & Ogg (1996), Sahagian et al. (1996), Hardenbol et al. (1998), and Haq (2014) is crucial to validate or refute them. To do that, forward stratigraphic modelling of one of the Mid-Pacific mountain guyots, Resolution Guyot, is performed. The study area is unique as it represents deposition of Cretaceous carbonates (growing at sea-level) on an isolated volcanic island away from the influence of continents and governed by a relatively simple thermal subsidence regime without tectonic uplift. The initial results show that Haq (2014) eustatic curve wasn't perfectly fitting some of our constraints, and some of the cycles need finer subdivision. The outcomes of this study will constrain the fluctuations of eustasy in the Cretaceous, and serve as a test to whether the amplitude and timing of regionally-derived eustatic curves (e.g. Rohl & Ogg, 1996; Sahagian et al., 1996; Hardenbol et al., 1998; Haq, 2014) are valid for other locations, or whether these curves are too influenced by specific local conditions in the areas.

References

- Haq, B. U. [2014]. Cretaceous eustasy revisited. *Global and Planetary Change*, **113**, 44-58.
- Hardenbol, J. A. N., Thierry, J., Farley, M. B., Jacquin, T., De Graciansky, P. C., & Vail, P. R. [1998]. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. *SEPM Special Publication*, **60**, 3–13.
- Röhl, U., & Ogg, J. G. [1996]. Aptian-Albian sea level history from Guyots in the western Pacific. *Paleoceanography*, **11(5)**, 595-624.
- Sahagian, D., Pinous, O., Olferiev, A., & Zakharov, V. [1996]. Eustatic curve for the Middle Jurassic--Cretaceous based on Russian platform and Siberian stratigraphy: Zonal resolution. *AAPG bulletin*, **80(9)**, 1433-1458.

11 - ANALYSING STATISTICAL PROPERTIES AND HETEROGENEITY OF HOLOCENE FRESHWATER DOLOMITES FROM HUNGARY USING CT DATA

Nour Alzoubi^{1*}-Sandor Gulyas¹-Janos Geiger¹

University of Szeged, Department of Geology and Paleontology, 2-6 Egyetem u. H6722 Szeged, Hungary

*e-mail: nouralzoubi@geo.u-szeged.hu

The formation of dolomite, especially in lacustrine environments is a unique phenomenon and the outcome of various geochemical, climatic, environmental factors. The general model of carbonate mineral formation in freshwater lakes has been defined in the 1970s, where the stability of the water level, pH, dissolved mineral content and ratio of Ca to Mg were all important components leading to the formation of calcite (Ca/Mg ratio <2), high magnesium calcite, proto-dolomite, dolomite (Ca/Mg ratio 2-7, 2-12) or dolomite, magnesite, huntite (Ca/Mg ratio > 12). Extensive freshwater carbonate sequences with a composition of dolomitic limestone and dolomite formed in interdune alkaline ponds of the Danube-Tisza Interfluvium in the middle part of the Carpathian Basin during the Holocene. These lakes are generally fed by groundwater, which dissolved Mg from the bedrock of windblown sands corresponding to reworked alluvial fan deposits of the Danube. During the summer because of extensive draughts water level drops, pH reaches values above 11 and dissolved mineral concentration ranges between 8-11,000 ppm. These conditions favor the precipitation of high magnesium calcite syngenetically turning into protodolomite, dolomite forming carbonate mud in the lakebed. Fall precipitation brings Ca-rich water into the desiccated ponds contributing to the diagenesis of carbonate mud leading to the formation of dolomite rocks. To understand the cyclicity present in the carbonate sequence we need quantitative information on the composition and physical properties of members of the sequence. This work presents preliminary results gained via the statistical analysis the physical properties of the freshwater carbonates by using CT technique. Heterogeneity of block samples was visualized and assessed based on Hounsfield units corresponding to density values gained from the CTs. Definition of the range boundary and distribution for carbonates was made using statistical, geostatistical tools.

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12 - MICROBIAL VERSUS ABIOTIC CONTROL ON MG- AND CA-CARBONATE PRECIPITATION AND DIAGENESIS: INSIGHTS FROM A MODERN HYDROMAGNESITE-MAGNESITE PLAYA, ATLIN, BC, CANADA

Tom Kibblewhite¹, Emily Junkins², Fiona Whitaker¹, and Bradley Stevenson²

¹ School of Earth Science, University of Bristol, Wills Memorial Building, Bristol, BS8 1RJ, UK

² Department of Microbiology and Plant Biology, University of Oklahoma, Norman, OK 73019, USA

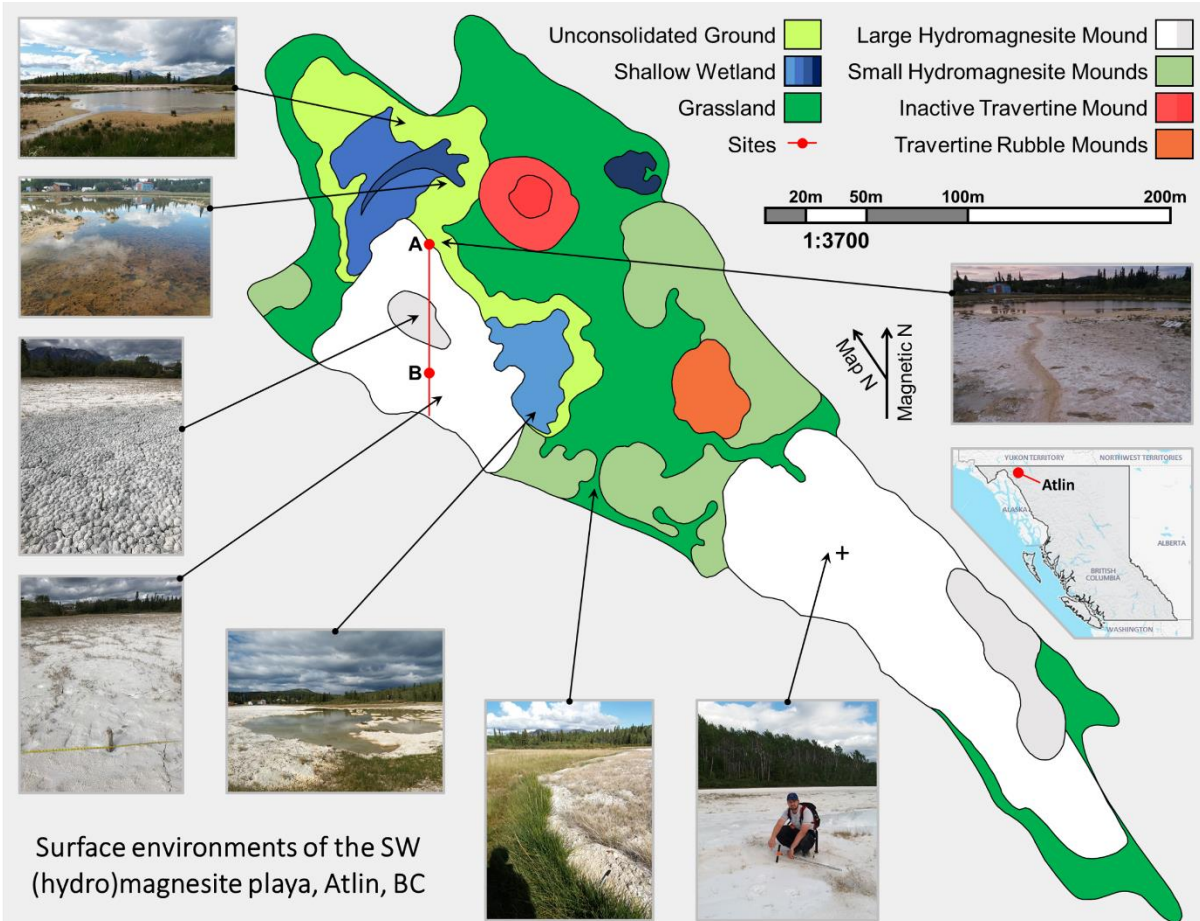
We investigate the importance of microbial and abiotic processes in the precipitation and early diagenesis of a hydromagnesite-magnesite playa in Atlin, BC, Canada, by characterising sediments, porewaters, and DNA. Hydromagnesite (Hmg; $[\text{Mg}_5(\text{CO}_3)_4(\text{OH})_2 \cdot 4\text{H}_2\text{O}]$) is a metastable hydrated Mg-carbonate, common in unevolved alkaline lakes on ultramafic terranes. As authigenic carbonate precipitates fill the hydrologically closed lake system, deposition shifts from anoxic subaqueous 'wetland' (Site A) to oxic subaerial 'Hmg mound' (Site B). Mound emergence and dehydration is reflected in transition from a smooth lake-margin surface (at Site A) to cauliflower-like structures and deep polygonal fractures at Site B. The large white Mg-carbonate mounds rise >1m above adjacent wetlands (10s cm deep), grasslands, smaller incipient hmg mounds, and a travertine mound.

Mg-HCO₃ groundwaters (8.1 pH) feeding the shallow playa are concentrated (~350%) by evaporation, forming surface brines of ~8.6 pH, ~4600 ppm HCO₃⁻, and ~1000 ppm Mg²⁺, and driving precipitation of hydrated Mg-carbonates and potential high-Mg dolomite precursors. Porewaters are similarly evapo-concentrated, relative to groundwaters, at the water table and to >700% in the near surface. Evaporation drives capillary rise; aiding CO₂ degassing and significant pH increase from 7.45 to 8.72 across 30 cm (Site A). In contrast, Site B chemistry varies little with depth (8.29 ± 0.11 pH over 80 cm). Site A porewaters record the highest SEC (10,000 μS/cm), HCO₃⁻, and Mg²⁺, all ~2.35x surface brines.

The 'wetland' site (A) is entirely anoxic, with a sequence of peaks in porewater redox species: O₂ at the surface, NO₃⁻ at 1.5 cm (1.10 ppm; water table), SO₄²⁻ at 5 cm (340 ppm), and CH₄ at 10 cm (1.15%) depth. Below the NO₃⁻ and SO₄²⁻ peaks, their reduced species (NH₄⁺ and S₂, evidenced by grey sediments) are dominant, and sediments become increasingly organic-rich. Above white, water table, sediments (1-2 cm depth), Site A's crystalline hydrated Mg-carbonate surface is coloured (clear, green, then red) by photosynthesisers. The subaerial 'Hmg mound' (Site B) is entirely oxic to a maximum sampled depth of 80 cm. All sediments are 'clayey' and 'pure' white, except for slightly yellowed coarsely crystalline intervals, representing cementation at previous water table positions (>60 cm). 16S RNA sequences (from both sites) indicates significant differences between microbial communities under oxic and anoxic, and subaerial and subaqueous conditions.

Mineralogical analysis showing transition from phreatic Ca- to vadose Mg-dominated carbonate precipitation is corroborated by modelling of porewaters in PHREEQC, incorporating reaction kinetics. PHREEQC is also used to infer changes in porewater chemistry and sediment mineralogy with water removal (evaporation or freezing) and CO₂ variation (degassing or microbial production).

This study shows that carbonate precipitation in alkaline playa lakes is controlled by a combination of factors. Biotic control (e.g. altering of porewater chemistry and provision of mineral nucleation sites) is less important in the oxic, unsaturated, and organic-poor mound, where the purest hydromagnesite precipitates. Porewater Mg/Ca ratio is the dominant abiotic control on carbonate mineralogy. Phreatic zone molar Mg/Ca is always <850 and precipitates are Ca-carbonates, but with continued infill and exposure vadose Mg/Ca is always >850 (up to 8900 ± 500) and Mg-carbonates precipitate.



13- DEPOSITION OF THE PRE-SALT “MICROBIALITE” IN THE KWANZA BASIN, ANGOLA

N. Rochelle-Bates.^{1*}, S. Schröder¹, R. Dixon²

1: Basin Studies and Petroleum Geoscience, University of Manchester, Manchester, United Kingdom

2: BP, United Kingdom

*Email: nathan.rochelle-bates@manchester.ac.uk;

The discovery of the South Atlantic “Microbialite” offshore Brazil (Parati field, Santos Basin 2005) has invigorated continental carbonate research and sparked renewed interest in the conjugate Angolan margin. These cryptic fibrous calcite precipitates are unprecedented as world-class petroleum reservoirs. The Angolan “Microbialite” and its Brazilian equivalent (the Barra Velha Fm) are characterized by spherulitic to shrubby fibrous calcite with variable amounts of Mg-clays. The unit is capped by a regionally extensive Aptian evaporite succession, which gives the “Pre-Salt” its name. The characteristic components of the “Microbialite” can be found over a large area. However, as more information enters the public domain, it appears that there were variable amounts of microbial influence and re-working processes. Restrictions on data access and publishing have resulted in different (and sometimes incompatible) depositional models. Many “Microbialite” accumulations have also experienced a complex diagenetic history, which obscures primary textural and geochemical features. This study focuses on a “Microbialite” core that was drilled in the distal part of the southern Kwanza Basin, Angola. Several petrographic and geochemical techniques were deployed to explore depositional variability within the cored interval.

The core is characterised by a variety of shrub, spherulitic and coated fibrous calcite facies, some of which have not been published in the public domain. Microbial macro textures of silicified/dolomitised stromatolitic fabrics and coated grains are rather common. A number of different re-worked fabrics are also present. Many previous studies only consider broad classifications of allochems (shrubs, spherulites, stromatolites, re-worked material) in their depositional models (e.g., Wright and Barnett, 2015). Others have pointed-out some variability within the fibrous calcite facies, without addressing the environmental significance of these structures (e.g., Sabato Ceraldi and Green, 2017). By integrating detailed facies observations with theory relating to fibrous calcite growth, it is possible to speculate on a variety of environments that could be represented by shrubs and spherulites in the Kwanza core.

Despite displaying the characteristic sweeping extinction under cross-polarized light, the spherulitic and shrubby calcite is recrystallized to varying degrees. Samples display some geochemical characteristics that could be interpreted as depositional. However, trace element and isotopic analysis reveal a mixed depositional–diagenetic signal. The results demonstrate the problems with extracting a “primary” geochemical signature and highlight the need to re-evaluate some of the existing interpretations from the Angolan and Brazilian “Microbialite”.

References

- Sabato Ceraldi, T., and Green, D., 2017, Evolution of the South Atlantic lacustrine deposits in response to Early Cretaceous rifting, subsidence and lake hydrology, *Geological Society, London, Special Publications*, v. **438**, p. 77–98, doi:10.1144/SP438.10.
- Wright, V.P., and Barnett, A.J., 2015, An abiotic model for the development of textures in some South Atlantic early Cretaceous lacustrine carbonates, *Geological Society, London, Special Publications*, v. **418**, p. 209–219, doi:10.1144/SP418.3.

14 - DEPOSITIONAL ENVIRONMENT AND DIAGENESIS IN THE BARRA VELHA FORMATION DEPOSITS AT OF THE BRAZILIAN PRE-SALT: NEW INSIGHTS FROM CARBON AND OXYGEN ISOTOPE ANALYSES

J.P. Gomes^{1,2}, A.C.L. Sartorato², L.R. Tedeschi², S.N. Tonietto², M.E. Tucker¹, F.F. Whitaker¹

1. School of Earth Sciences, University of Bristol, Queens Road, Bristol BS8 1RJ, England.
2. Reservoir team, Petrobras S. A., Centro Empresarial Senado, 7 andar, Torre B, Avenida Henrique Valadares, 28, centro, Rio de Janeiro, 20231-030, Brazil

Links between depositional facies and diagenetic products of the Aptian lacustrine carbonates of the Santos Basin have been investigated in order to evaluate their genesis. In-situ carbonates comprise a range of facies that are defined according to the different proportion of three end-member components: (1) calcite shrubs; (2) calcite spherulites; (3) muds composed of calcite-dolomite and/or Mg clay. The dominant diagenetic components are a range of texturally-distinct types of dolomite: rhombohedral, anhedral, lamellar and saddle. In addition, diagenetic silica minerals occur such as chalcedony, microcrystalline quartz and coarse crystalline quartz with different textures such as mosaic, lamellar, fibrous and botryoidal fabrics. The abundance of each of these diagenetic textures has been analysed in 1700 thin sections from 8 wells from the Barra Velha Formation (BVF) in a particular Pre-Salt field.

Rhombohedral dolomite is common in all identified facies and in all wells, whereas lamellar dolomite occurs exclusively in association with spherulite-rich facies and shows a typical 'microbial filamentous-like texture'. Mudstones have the lowest isotopic compositions of all of the facies ($< 0\%$ for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values). Spherulite-rich facies define a comparatively enriched domain with values of both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values ranging from 0 to $+4\%$. Shrub-rich facies have isotopic values intermediate between those obtained from mudstones and spherulite-rich facies. Assuming that these carbonates are formed in thermodynamic equilibrium with depositional and/or early diagenetic pore waters, the higher $\delta^{18}\text{O}$ values of the spherulite-rich facies suggest that they have been formed from waters that have experienced higher evaporation rates and/or cooler temperatures. Mudstones have been formed during periods when the lacustrine dilution was warmer and/or had lower $\delta^{18}\text{O}$ values due to lower evaporation rates. Rhombohedral dolomites show a positive correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values and are interpreted to have formed during very early diagenesis. A later anhedral dolomite, formed after the rhombohedral dolomite, has lower $\delta^{18}\text{O}$ values that suggest formation at a higher temperature (c. 8°C warmer than the rhombohedral dolomite) and/or from different pore waters.

The distribution of diagenetic minerals, and bulk isotope values show that the degree of replacement of calcite by dolomite does affect the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotope values, suggesting care must be taken in using bulk rock isotope values to interpret the Barra Velha depositional environment. Nevertheless, spatial and temporal variations in isotope values for shrubs, spherulites and dolomites can provide new insights into depositional environment and early diagenesis. Within the upper portion of the Barra Velha Formation (above the Intra-Alagoas Unconformity) a clear more positive trend in both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values indicates a gradual upward change towards a drier climate. The uppermost unit of the BVF consists of an alternation of calci-mudstone and dolo-mudstone (12 m thick), with more negative $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values; this is related to an increased input of meteoric water and/or reduced evaporation, prior to flooding by marine waters and deposition of the succeeding salt of the Ariri Formation.

15 - PETROLOGICAL, GEOCHEMICAL AND MORPHOLOGICAL CHARACTERISTICS OF MODERN AND ANCIENT LACUSTRINE MICROBIAL CARBONATES OF THE IBERIAN PENINSULA

*Connor Doyle*¹, *Stefan Schröder*¹, *Juan Pablo Corella*², *Blas Valero Garces*³, *Julia Behnsen*⁴

1 - Department of Earth and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK.

2 - Universite Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, 38000 Grenoble, France

3 - Instituto Pirenaico de Ecologia, Zaragoza, Spain

4 - Henry Moseley X-Ray Imaging Facility, Department of Materials, University of Manchester, UK

connor.doyle@postgrad.manchester.ac.uk

Microbial mats represent a model ecosystem to study microbial interactions with carbonates, to understand early diagenesis of microbialites, and to act as analogues for microbialitic fabrics occurring within unconventional hydrocarbon reservoirs. The numerous saline-alkaline lakes of the Iberian Peninsula which contain many of these structures consequently represent a natural laboratory in which they can be studied [1]. The aim of this study was to characterise the morphological, petrographical and geochemical characteristics of modern (1-20 years) and ancient (~1000-10000 years) microbial mats from a range of Iberian hypersaline-alkaline lacustrine settings and to determine the extent of geochemical and diagenetic controls acting on these deposits. Chosen sites include Laguna Salada de Chiprana, NE Spain, for the study of modern and sub-recent mats, and Lago de Arreo, Laguna Zonar and Lago de Estanya, NW, S and NE Spain respectively, for the study of microbialites within the Late Holocene. The study hypothesises that comparisons of mats from these settings will permit an increased understanding of environmental controls acting upon these deposits. Namely, this will include how biotic and abiotic processes contribute to carbonate formation in microbial mats, the presence and timescales upon which diagenesis act within these deposits, and the environmental thresholds associated with the occurrence of microbial mats and microbialites in the rock record.

Microscopic and bulk geochemical analyses indicate a varying predominance of aragonitic and high-Mg CaCO₃ phases coupled with the occurrence of gypsum, hexahydrite (MgSO₄·6H₂O) and thenardite as evaporitic phases. Petrographical observations reveal a spectrum of laminated and clotted textures and concentration of magnesian and calcitic carbonates within microbially-formed laminae. Distinctive variations in petrography and particularly mineralogy can be attributed to an interplay of geochemical and microbial controls acting within each system. High but varying concentrations of Ca and Mg within these mats as illustrated by SEM-EDS suggest differential concentration of Ca²⁺ ions and subsequent carbonate precipitation within microbial EPS and micrite matrices. From a purely geochemical perspective, shifts in the abundance of calcite and aragonite reflect varying Ca-Mg ratios and lake level changes. Changes in the abundance of hexahydrite and gypsum reflect large-scale lake drawdown and progressive evaporative concentration of Mg²⁺, SO₄²⁻, Na⁺ and Ca²⁺ ions. The morphology of modern and ancient mats characterised using X-ray CT scanning furthermore illustrates significant variability between distinctive settings, and mats from each setting display micro-spatial variations in their morphological characteristics, and yields insights into pore-permeability networks within these unique deposits. In all cases, periods of microbial mat formation and associated carbonate precipitation can be attributed to the onset of several key environmental conditions; namely elevated salinities, lake drawdown, and reduced competition from grazing predators. However, variations in the mineralogy, sedimentological fabrics and morphogenesis of mats from lacustrine systems of varying geochemistry and age highlight the effect of distinct environmental and geochemical conditions upon mat formation, carbonate mineralogy and petrography, and diagenesis.

Guerrero, de Wit, & Wit. (1992). Microbial mats in the inland saline lakes of Spain. *Limnetica*.

16 - THE CONTROL OF PO₄ ON NEOPROTEROZOIC MARINE CARBONATES

S. Roest-Ellis¹, R. Pietzsch¹, O. Gaitonde¹, J. Strauss², J. Richardson³, S. Webb³, B. Phillips⁴ & N. Tosca¹

¹Department of Earth Sciences, University of Oxford, Oxford, OX1 3AN, United Kingdom

²Department of Earth Sciences, Dartmouth College, Hanover, NH 03755, USA

³SLAC National Accelerator Laboratory, Stanford University, CA 94025, USA

⁴Department of Geosciences, Stony Brook University, NY 11794-2100, USA

sascha.roest-ellis@spc.ox.ac.uk

Varying styles of nucleation and crystal growth preserved in Precambrian aged carbonates reflect secular changes in CaCO₃ production [1]. For example, Mesoproterozoic and early Neoproterozoic aged carbonates (ca. 1,600–720 Ma) record the progressive replacement of Archean and early Proterozoic seafloor precipitates by microcrystalline CaCO₃ mud (or micrite). Although generally agreed to reflect a locus shift from CaCO₃ seafloor precipitation to CaCO₃ water column nucleation [1], the associated environmental transition and its impact on the global carbon cycle, are unknown.

Here, leveraging recent Neoproterozoic seawater chemistry constraints from fluid-inclusions [2] and authigenic Mg-silicates [3], we examine CaCO₃ nucleation from Neoproterozoic seawater in the presence of a key modifying compound – PO₄. Experiments show that aragonite consistently nucleates at Ω_{Calcite} of ~20-30 independently of dissolved inorganic carbon (DIC) and alkalinity. However, when [PO₄] > ~12 $\mu\text{mol/kg}$, nucleation of both aragonite and calcite is inhibited. Nucleation only then occurs at Ω_{Calcite} > ~45 as amorphous CaCO₃ (ACC). Because ACC is unstable, it recrystallises to high-Mg calcite (HMC) and/or monohydrocalcite, dependent upon Mg/Ca ratio, DIC, and pH.

Together, our experimental data provide new insight into the processes that generated finely crystalline CaCO₃ from late Proterozoic seawater. For example, the transformation of ACC → Mg-calcite at solution Mg/Ca ratios >2 is consistent with petrographic and geochemical characteristics of syndimentary calcite microspar cement, a common depositional fabric and building block of mid-Neoproterozoic carbonates [4]. Nevertheless, to place these results in a geological framework, we conducted PO₄ analyses of microspar-dominated carbonates from multiple mid-Neoproterozoic successions (~800 Ma). Bulk PO₄ analyses provide consistent evidence of [PO₄] > 1000 ppm – far higher than modern ooids (where [PO₄] = ~75 ppm). Synchrotron-based XANES and μXRF observations, combined with SEM-EDS, and solid state ³¹P-NMR, show PO₄ is bound principally in carbonate fluorapatite (CFA); deposited as seafloor syndimentary cements, within Mg-silicate-rich intraclasts, nano-inclusions within microspar cement and talc, and as disseminated detrital particles. Our data show that PO₄ is dominantly carbonate-associated, and only rarely associated with ferric-iron oxide/organic matter in these mid-Neoproterozoic samples; Fe and S-bearing diagenetic minerals, the products of anoxic respiration, are rare to absent.

These data suggest that the enhanced [PO₄] in Neoproterozoic seawater may have permitted non-classical CaCO₃ nucleation at high Ω_{Calcite} , in turn producing syndimentary microspar, authigenic Mg-silicates [3], and CFA. In fact, the stratigraphic abundance of microspar peaked in the early Neoproterozoic [4], indicating that this threshold was repeatedly crossed across multiple basins. This uncovers the mechanisms underpinning a shallow water CaCO₃ factory that was perhaps the most dynamic in Earth's history. Furthermore, geological evidence of the CaCO₃–PO₄–Mg-silicate relationship reveals that mid-Neoproterozoic seawater featured enhanced bioavailable marine PO₄. This carries a number of implications for the global P-cycle, on the cusp of early eukaryotic diversification.

References

[1] Grotzinger, J.P and James, N.P. (2000), *SEPM SPEC P*, **67**, pp. 3-20 ; [2] Spear, N., et al. (2014), *GEOLOGY*, **42**, pp. 103-106; [3] Strauss, J.V. and Tosca, N.J., (*in press*), *GEOLOGY*; [4] James, N.P., et al. (1998), *J SEDIMENT RES*, **68**, 716-722.

17 - A CRETACEOUS ALKALINE LAKE AS AN ANALOGUE FOR THE PREBIOTIC P-CYCLE?

Raphael Pietzsch^{1,2}, Sascha Roest-Ellis¹, Nicholas J. Tosca¹

¹Department of Earth Sciences, University of Oxford, Oxford, OX1 3AN, UK

²Petrobras Research and Development Centre (Cenpes), Rio de Janeiro, RJ, Brazil

Phosphorus as phosphate comprises the backbone of extant metabolism, cell physiology, and genetics, being fundamental to biochemical energy transfer through adenosine triphosphate (ATP), to cell compartmentalization as phospholipids in cell walls, and to the structure of RNA and DNA [1–3]. Despite this central importance, it is not readily available in most rocks and apart from a few minerals of the apatite group that are common accessory minerals in almost all igneous rocks [4], it is not an abundant element in the Earth's crust, comprising just 0.09 wt% [5]. Under present-day Earth conditions, phosphorus has no stable atmospheric gas phases, so unlike the case for other critical bionutrients, such as nitrogen and carbon, ecosystems depend entirely on its aqueous transfer [5].

Exactly how phosphorus became involved in prebiotic chemistry has long persisted as a conundrum [6]; this has been dubbed “the phosphate problem” [2,7]. In the presence of Ca²⁺ ions, phosphate readily precipitates as highly insoluble apatite [8]. This has led to the consideration of whether reactive reduced phosphorus species may have supplied soluble phosphorus, as well as an energetically favourable substrate for biochemical reactions [6]. But regardless of its chemical form, we have a poor understanding of the early P cycle on Earth, its links to plausible prebiotic scenarios, and their dependence on the composition of the primitive ocean, atmosphere, rocks and minerals [9–12]. However, a recent study highlighted the tendency of some modern-day alkaline lakes to scavenge Ca²⁺ from solution through carbonate precipitation, in turn leading to a build-up of phosphate in solution, preventing the precipitation of apatite [7]. This implies that the interplay between carbonate geochemistry and phosphate may reveal plausible prebiotic scenarios for concentrating soluble phosphorus.

In this study we investigate a Lower Cretaceous alkaline lake, which has seen no modern analogue in terms of areal distribution and thickness; it comprises one of the largest lacustrine carbonate deposits known to date. These deposits were influenced by tectonic events, as a result of the rifting of the Gondwanan continent, as well as generally dry climatic conditions in its interior, resulting in unusual lake chemistries featuring considerably alkaline lake waters perhaps approaching values estimated for early Earth environments [7]. These are indicated by the fossil record, isotopic data, the presence of Mg-silicate clay mineral deposits (sometimes completely dissolved and/or replaced) – and unusual calcite morphologies (fascicular crusts and spherulites), as well as dolomite [13 and references therein].

We examine here the role of phosphorus in influencing unusual styles of carbonate precipitation and evaluate whether these depositional and chemical conditions featured phosphorus/phosphate build-up. By combining geological and geochemical observations with laboratory experiments, we evaluate whether this depositional system might offer a rare glimpse of geological conditions that occurred across other periods of Earth history where the sedimentary record has been largely erased.

References

- [1] Benner & Hutter 2002, *Bioorg Chem* **30**, 62–80; [2] Burcar et al. 2016, *Angew Chem* **55**, 13249–13253; [3] Kamerlin et al. 2013, *Q Rev Biophys* **46**, 1–132; [4] Chang et al. 1996, *Rock-Forming Minerals*, Vol 5B, 2nd Ed; [5] Fillippelli 2008, *Elements* **4**, 89–95; [6] Pasek 2008, *PNAS* **105**, 853–858; [7] Toner & Catling 2020, *PNAS* **117**, 883–888; [8] Smith & Morowitz 2016, *The Origin and Nature of Life on Earth*, Cambridge University Press; [9] MacLeod et al. 1994, *Origins Life Evol B* **24**, 19–41; [10] Russell & Hall 2006, *Geol Soc Am Mem* **198**, 1–32; [11] Hazen 2006, *Am Mineral* **91**, 1715–1729; [12] Martin & Russell 2007, *Philos T R Soc B* **362**, 1887–1925; [13] Pietzsch et al. 2020, *Chem Geol* **535**.

18 - DATING RECORDS OF PAST SEAFLOOR METHANE EMISSIONS ALONG THE U.S. ATLANTIC MARGIN

Diana Sahy¹

1 – Geochronology and Tracers Group, British Geological Survey, Keyworth, NG12 5GG, UK

Methane-derived authigenic carbonates (MDAC) are the only available archive of past methane emissions from seafloor cold seeps into the ocean. U-Th dating of MDAC can shed light on regional patterns in subsurface methane-rich fluid migration, but the logistics of MDAC sampling hamper the development of datasets with adequate geographic coverage and spatial resolution. Additionally, the interpretation of MDAC U-Th data is complicated by the need for often significant corrections to account for U and, more importantly, Th input from seafloor sediments and bottom water.



Figure 2 Active methane seep at the Chincoteague seep field offshore Virginia, ~1000 m below sea level. Photo courtesy of the U.S. Geological Survey

Here we present preliminary results obtained on MDAC crusts collected from eight active seep fields along a 1000 km stretch of the U.S. Atlantic margin, at 300 – 2200 metres below sea level, using Deep Submergence Vehicle Alvin. The samples were collected during the 2015 SeepC expedition, and were analysed as part of a collaborative project led by the US and British Geological Surveys.

Samples consist of 30 – 80% aragonite and/or calcite cements encasing silt to gravel-sized detrital silicates. Interconnected voids within the MDAC crusts, which likely represent fluid conduits, are partially filled with relatively younger, clean (>90%), layered aragonite. Multiple generations of carbonate were selected for U-Th analysis in order to obtain a complete picture of seepage dynamics at each locality. However, younger and cleaner carbonate domains were more likely to yield usable results than older crust samples which typically have a higher detrital silicate content, and therefore the data only provide minimum age constraints for the onset of individual seepage episodes.

We evaluated the accuracy of our U-Th dates based on agreement between age data and textural relationships within each MDAC, and comparisons between the calculated initial ($^{234}\text{U}/^{238}\text{U}$) of the fluid from which the MDAC precipitated and modern seawater. Using this approach, we were able to produce a dataset of ca. 100 U-Th dates. We found that shallow continental shelf seeps (300 – 400 mbsl) have been active since ~16 ka, while deep-water seeps (>1000 mbsl) are mostly younger than 4 ka. The relatively low geographic coverage and high likelihood of sampling bias makes it difficult to link seepage episodes to specific warming events that occurred since the Last Glacial Maximum, but it appears that position relative to the boundaries of the gas hydrate stability zone, bottom water warming, the presence/absence of underlying salt diapirs, and proximity to the formerly glaciated New England margin were the main controls on methane seepage along the US Atlantic margin.

19 - MIXING OF CONTINENTAL WATER MASSES IN THE HAMPSHIRE BASIN DURING MECO: NEW INSIGHT FROM CARBONATE CLUMPED ISOTOPES

Marta Marchegiano¹ and Cédric M. John¹

¹*Department of Earth Science and Engineering, Imperial College London, UK*

Delineating the response of different environments to changes in temperatures is crucial to predict the impact of future climate warming. The hydrological cycle is of particular importance, as it influences rates of erosion and impact freshwater discharges on continental margins. Here, we present clumped isotopes (Δ_{47}) and stable isotopes ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) data from 14 well-preserved, aragonitic molluscs and gastropods samples from the Middle Eocene Barton Clay Formation (Hampshire Basin, Barton on the sea, UK). The Hampshire Basin is the northwesterly component of the larger Anglo-Paris-Belgium Basin and represent one of the best preserved Paleogene sequence worldwide. The Barton Clay Formation has been studied to assess variation on the paleoshoreline as well as in temperatures during Middle Eocene: our interest is to understand the link between climate, and the oxygen isotope composition of seawater in this basin (a proxy for input of continental freshwater).

Carbonate Clumped isotopes is based on the temperature-dependent abundance of ^{13}C - ^{18}O bonds in CO_2 (expressed as Δ_{47}), a measure directly correlated to the temperature of precipitation of carbonates. Using clumped isotope data and the $\delta^{18}\text{O}$ of the sample, the isotopic water composition ($\delta^{18}\text{O}_w$) can be directly calculated. In continental margins, the seawater $\delta^{18}\text{O}$ composition is influenced by the mixing of riverine and marine waters in addition to environment temperatures. Clumped-isotopes, unlike oxygen isotopes, are not sensitive to changes in the water oxygen composition and thus allow to disentangle this temperature from water composition.

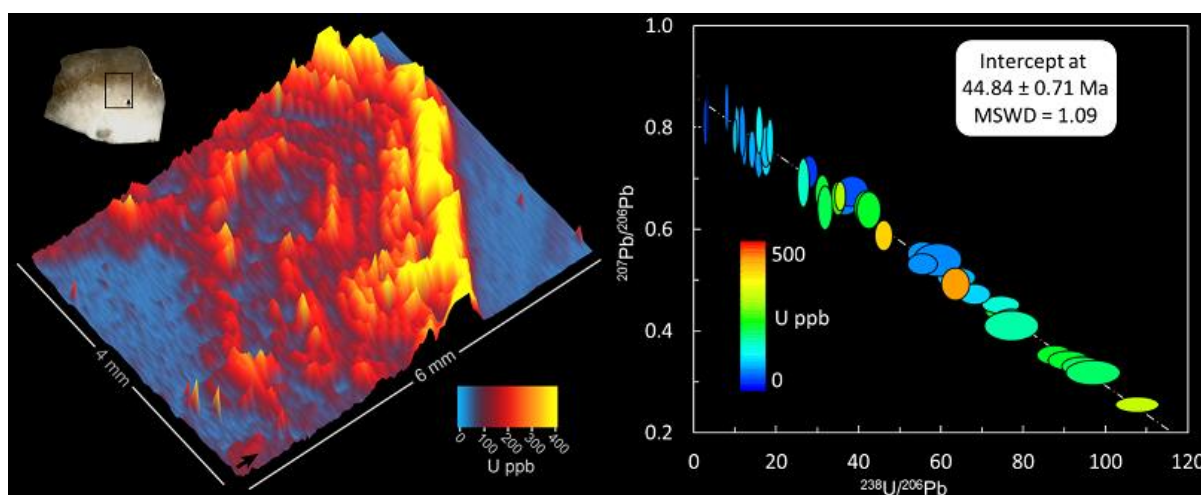
Our preliminary results confirm the presence of the Middle Eocene Climatic Optimum (MECO) event (a 2‰ negative $\delta^{13}\text{C}$ excursion starting ~20m upsection). The MECO is a global warming anomaly that has been recorded worldwide and dated to ~40Ma. Data from the base of the section (pre-MECO) suggest more brackish conditions ($\delta^{18}\text{O}_w$ of $-5.50\text{‰} \pm 0.5$), associated with relatively low-temperature of $13^\circ\text{C} \pm 2^\circ\text{C}$. Up section, at the base of the Middle Barton Beds, more marine $\delta^{18}\text{O}_w$ values are recorded. A general increase of temperature is also observed (max T of $32 \pm 5^\circ\text{C}$), interspersed with a few cold events with temperature of $13^\circ\text{C} \pm 3^\circ\text{C}$. During the MECO event, clumped-isotopes analyses record temperature of $27 \pm 1^\circ\text{C}$, and normal marine $\delta^{18}\text{O}_w$ values. Our quantitative benthic fauna analysis (i.e. ostracods, molluscs and gastropods) shows very low species richness index (SRI) in the lower part of the outcrop (in the brackish conditions), followed by a drastic increase in SRI up section, where our reconstructed oxygen isotope values of seawater suggest more marine conditions. This increase in marine values could be indicating a deepening of water depth in the basin starting from the middle of the Middle Barton Beds and up into the MECO event. We conclude that clumped isotopes data successfully recorded changes in temperature and input of continental freshwater into the basin: this approach thus has tremendous potential in reconstructing paleoclimate on continental margins.

20 - DATING CARBONATES WITH IN SITU U-Pb GEOCHRONOLOGY (POSTER)

Nick M W Roberts

Geochronology and Tracers Facility, British Geological Survey, Nottingham, NG12 5GG, UK
nirob@bgs.ac.uk

Until recently, absolute geochronological constraints on carbonate formation have been restricted to U-Th dating of young (<600 ka) samples, and to a handful of studies using traditional Sm-Nd, Pb-Pb and U-Pb dissolution methods. In the last few years, following the development of a suitable reference material (Roberts et al., 2017), the in situ technique - laser ablation ICP-MS, has opened up the possibilities for U-Pb dating of carbonates formed in a wide variety of settings. Here I discuss why LA-ICP-MS has been beneficial to developments in U-Pb carbonate geochronology, and I review the breadth of applications across a significant span of geological time. I will showcase examples that include the dating of speleothems, the timing of diagenetic mineral formation and associated hydrocarbon charging, dating of fault-related precipitates and the timing of primary carbonate deposition; with these examples ranging in age from the Quaternary to the Proterozoic.



Dating of a fracture-filling calcite vein, Faroe Islands. Figure shows a photograph of the sample, an elemental map generated using LA-ICP-MS, and a Tera-Wasserburg concordia plot showing the obtained age and 2s uncertainty.

References

Roberts, N.M.W., Rasbury, E.T., Parrish, R.R., Smith, C.J., Horstwood, M.S.A. & Condon, D.J., 2017, A calcite reference material for LA-ICP-MS U-Pb carbonate geochronology, *Geochemistry, Geophysics, Geosystems*, **18**, 2807-2814.

21 - A METHOD FOR CONSTRAINING FLUID ADVECTION RATES ON CARBONATE PLATFORMS USING CALCIUM AND CLUMPED ISOTOPES

Philip T. Staudigel

The advection of fluid into carbonate sediments constitutes an important flux for ventilating the uppermost sediments, as well as providing ions for exchange in many diagenetic reactions. Geothermal convection of fluids (Kohout convection) is a commonly attributed mechanism for driving the advection of fluid into the flank of carbonate platforms, where it is drawn into the platform interior, heated, then transported vertically. This mechanism is sensitive to the geometry of the platform margin, where less steep geometries would be expected to have weaker advection rates. The leeward margin of Great Bahama Bank (sampled by ODP Site 1003), which transitioned from a carbonate ramp to a steeper-margined platform during the mid-Miocene provides a useful natural laboratory to test this theory. An existing dataset of clumped isotopes (Staudigel and Swart, 2019) was used to constrain the reactivity of sediments, these values were used in a reaction diffusion-advection model for calcium isotopes which was tuned to an existing dataset of measured $\delta^{44}\text{Ca}$ values (Higgins et al., 2018). Because the reactivity of sediments is constrained using clumped isotopes, it is possible to calculate the advection rate of seawater at the sediment-water interface. This technique should be applicable to any carbonate unit wherein the reactivity can be constrained. Results show that sediments rapidly undergo an early recrystallization, facilitated by the neomorphism of metastable aragonite to calcite at an initial rate of 70 %/myr which decreases over time. Diagenetic models indicate a strong increase in fluid advection velocity from $<0.3\text{cm/yr}$ up to $\sim 30\text{cm/yr}$, over a time period wherein the leeward margin of GBB transitioned into a steeper slope angle. Several pulses of advection can be resolved, each lasting $\sim 1\text{Myr}$, separated by several Myr of diminished advection. Some of these pulses correspond to transitions from finer-grained sediments to coarser sediments, possibly reflecting a localized increase in advection. The most recent decrease appears to correlate with the periodic exposure of the platform top. The transition to a steeper margin was driven by the onset of modern benthic currents in the region 10-14 Ma which was associated with a global re-arrangement of many carbonate platforms (Betzler et al., 1999; Betzler and Eberli, 2019). The rapid change in the magnitude of advection on the margin fundamentally changed the behaviour of diagenetic processes within the platform by facilitating the supply of ions for reactions such as dolomitization. This behaviour, therefore, would be expected in other carbonate systems which have undergone similar upheavals in sedimentary structure.

References:

Betzler, C., Eberli, G.P., 2019. Miocene start of modern carbonate platforms. *Geology* 47, 771–775. <https://doi.org/10.1130/G45994.1>

Betzler, C., Reijmer, J.J.G., Bernet, K., Eberli, G.P., Anselmetti, F.S., 1999. Sedimentary patterns and geometries of the Bahamian outer carbonate ramp (Miocene-Lower Pliocene, Great Bahama Bank). *Sedimentology* 46, 1127–1143. <https://doi.org/10.1046/j.1365-3091.1999.00268.x>

Higgins, J.A., Blattler, C.L., Lundstrom, E.A., Santiago-Ramos, D.P., Akhtar, A.A., Cruger Ahm, A.S., Bialik, O., Holmden, C., Bradbury, H., Murray, S.T., Swart, P.K., 2018. Mineralogy, early marine diagenesis, and the chemistry of shallow-water carbonate sediments. *Geochim. Cosmochim. Acta* 220, 512–534. <https://doi.org/10.1016/j.gca.2017.09.046>

Staudigel, P.T., Swart, P.K., 2019. A diagenetic origin for isotopic variability of sediments deposited on the margin of Great Bahama Bank, insights from clumped isotopes. *Geochim. Cosmochim. Acta* 258, 97–119. <https://doi.org/10.1016/j.gca.2019.05.002>

22 - CONTROLS ON THE LOCALISATION OF FAULT/FRACTURE CONTROLLED DOLOMITIZATION: INSIGHTS FROM THE DERBYSHIRE PLATFORM, LOWER CARBONIFEROUS, UK

C.Breislin¹, C.Hollis², I.Millar³, V.Banks³, J.Riding³

1. Badley Ashton and Associates, Winceby House, Winceby, Horncastle, Lincolnshire, LN9 6PB, UK

2. School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Williamson Building, Manchester M13 9PL, UK

3. British Geological Survey, Environmental Science Centre, Keyworth, Nottingham NG12 5GG, UK

The Derbyshire Platform is a Mississippian rimmed shelf, the westernmost expression of the East Midlands Platform. On the SE platform margin, 60km² of Visean limestones have been dolomitized, forming two major bodies along major NW – SE trending basement lineaments and extrusive volcanic beds. The body on the southern margin on the Derbyshire Platform is one of several discrete, fault-fracture controlled dolostone bodies that occur on Mississippian platform margins across the Pennine Basin and North Wales. Dolomitization is known to predate mineralisation but uncertainty lies as to why the dolomitization is localised.

This study uses outcrop, petrography, geochemistry and isotopic analysis to better constrain the timing and mechanism for dolomitization on the southern margin of the Mississippian Derbyshire Platform. Field relationships demonstrate fault-fracture controlled dolomitization is multi-phase (D2 – D5) and constrained to fault damage zones of major strike-slip faults. Fluids for dolomitization were sourced from the surrounding basins, initiated after the main phase of porosity occluding calcite cementation on the Derbyshire Platform, and terminating prior to the main phase of mineralisation.

Results from this study demonstrate that strike-slip crustal faults were reactivated during basin inversion at the onset of the Variscan Orogeny, leading to the localisation of the dolostone on the platform. Fluid supply was episodic, as these faults were reactivated through the ongoing compressive regime, leading to several discrete phases of dolomitization that became increasingly confined to fractures. Geochemical and isotopic analysis show that low fluid-rock ratios resulted in rock buffering of dolostone isotopic signatures.

Timing of dolomitization is interpreted to be a Carboniferous event, with later mineralisation also being of late Carboniferous in age. This study demonstrates the complex interplay between basin kinematics, host rock permeability and timing of fluid supply through episodic fault reactivation, connecting platforms to basin compartments, which ultimately controlled the positioning of dolostone geobodies on platform margins. Dolomitization is seen to provide a record of fluid flow during the transition from thermal subsidence to post-rift basin inversion. This has implications to the exploration of both minerals and hydrocarbon within dolostone hosts, and will inform studies of fluid transfer and reaction on carbonate platforms within the burial realm.

23 - HIGH-TEMPERATURE FAULT-CONTROLLED DOLOMITISATION BY CONVECTION OF SEAWATER: CONCEPT EVALUATION USING REACTIVE TRANSPORT MODELLING

Rungroj Benjakul¹, Cathy Hollis², Hamish A. Robertson¹, Eric L. Sonnenthal³, Fiona Whitaker

¹School of Earth Sciences, University of Bristol, Queens Road, Bristol BS8 1RJ, UK

²School of Earth and Environmental Science, University of Manchester, Manchester M13 9PL, UK

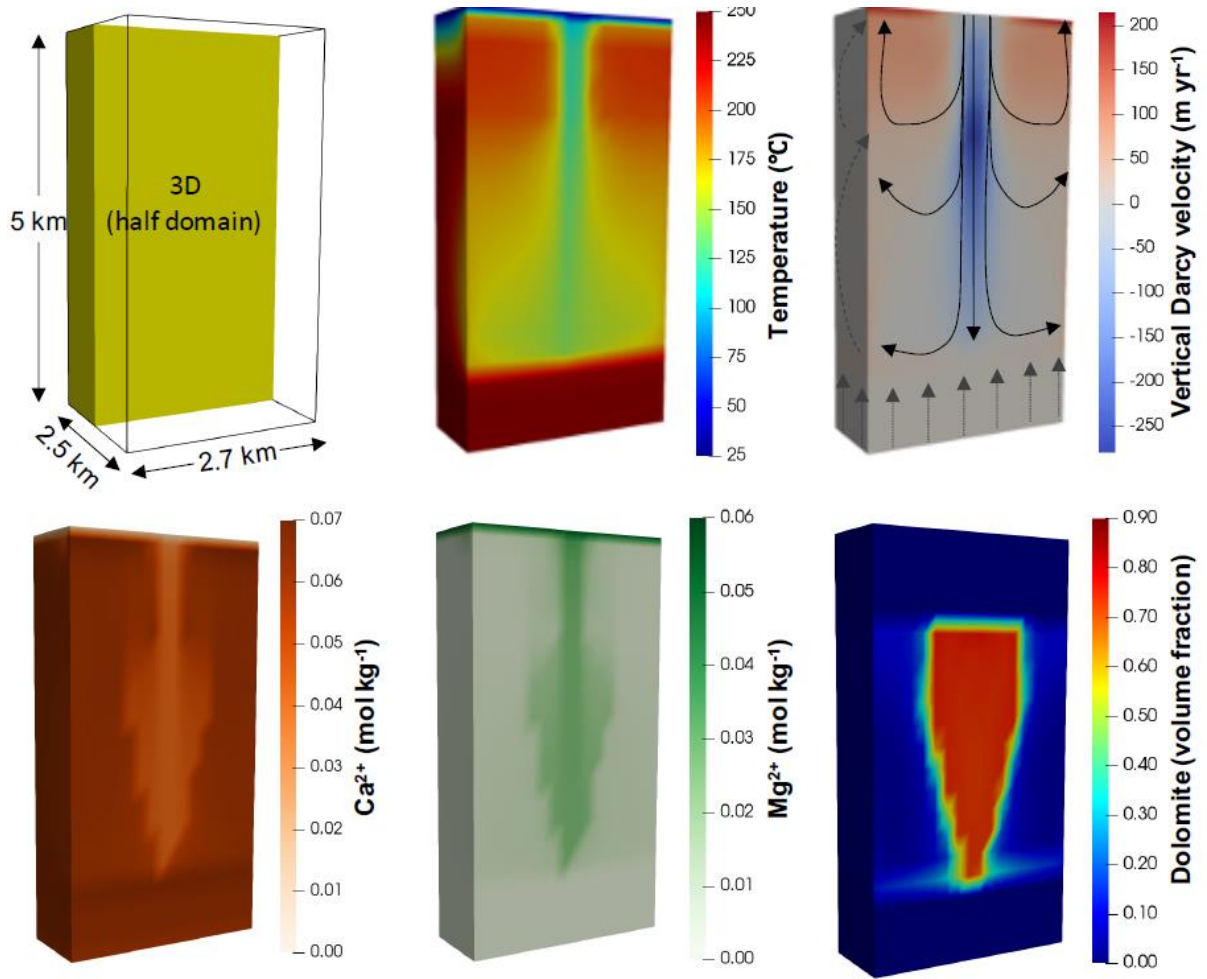
³Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

The dominant paradigm for the formation of high-temperature fault-controlled dolomite, widely known as “hydrothermal” dolomite, invokes upwelling of hot fluid along faulted and fractured conduits from a deep overpressured aquifer. However, this model has a number of inherent ambiguities with respect to the fluid sources and their dolomitisation potential, as well as mechanisms for delivering sufficient amount of these reactive fluids to form substantial volumes of dolomite. Here, we evaluate an alternative conceptual model of high-temperature fault-controlled dolomitisation driven by top-down convection of seawater in a single transmissive fault system using a reactive transport model (RTM) approach.

The simulations conducted using TOUGHREACT suggest that it is possible for convection of seawater along the fault damage zone to form massive dolomite bodies that extend hundreds of meters vertically and along the fault within a timescale of a few tens of kyr, with no significant alteration of the country rock. Dolomitisation occurs as a gradient reaction by replacement of host limestones and minor dolomite cementation, and results in discharge of Mg-poor, Ca-rich fluids to the sea floor. Fluids sourced from the basement contribute to the transport of heat that is key for overcoming kinetic limitations to dolomitisation, but the entrained seawater provides the Mg to drive the reaction.

Dolomite fronts are sharper on the “upflow” margin where Mg-rich fluids first reach the threshold temperature for dolomitisation. In comparison, the “downflow” dolomite front tends to be broader as reaction rates here are slower as the fluid is depleted in Mg by prior dolomitisation. The temperature of dolomitisation in the core of the dolomite body is relatively high (130–150 °C), but within the “upflow” area dolomitisation initially occurs at considerably lower temperatures (80–100 °C). In contrast, the “downflow” margins record later-stage increase in dolomitisation temperature to 180–190 °C. Such contrasts in the temperature of dolomitisation at a single location are commonly observed in fault-controlled dolomites and can be interpreted in terms of major shifts in the system driving dolomitisation. Our simulations demonstrate that these are a product of “emergent behaviour” within a relatively stable system, and arise from the dynamic nature of the coupled system, with areas that are dolomitised more slowly recording the effect of changes in fluid flow, heat and solute transport that occur in response to diagenetic permeability modification.

Systems that are governed by complex interactions between physical and chemical processes, are challenging to predict or quantify *a priori*. In scenarios where direct observation of flow and chemistry in natural settings is challenging, simulations that represent the coupled nature of these processes offer a route to evaluate conceptual models. In this case they robustly demonstrated that high-temperature fault-controlled dolomite bodies can form from circulating seawater. In addition, comparison of our 3D simulations with simplifications to 2D, either perpendicular or parallel to the strike of the fault, illustrate how 2D models misrepresent critical aspects of the system. This has important implications for modelling of systems ranging from geothermal resources and mineralisation to carbonate diagenesis, including hydrothermal karstification as well as dolomitisation.



Simulation results of baseline 3D model showing heat transfer, fluid flow, concentrations of Mg^{2+} and Ca^{2+} , and dolomite distribution at 30 kyr.

24 - RECONSTRUCTING FLUID CIRCULATION PATHWAYS IN VOLCANICALLY INFLUENCED SETTINGS: A CASE STUDY FROM THE NAMIBE BASIN (ANGOLA) (POSTER)

Fiordalisi Edoardo¹, do Couto Pereira Gustavo¹, Rochelle-Bates Nathan¹, Marchegiano Marta², John Cédric², Dixon Richard³, Sharp Ian⁴, Schröder Stefan⁴.

1: University of Manchester; 2: Imperial College London; 3: BP Exploration; 4: Equinor Exploration Research and Technology.

edoardo.fiordalisi@manchester.ac.uk, University of Manchester, Department of Earth and Environmental Sciences, Oxford Road, Manchester, M13 9PL.

The Namibe Basin is the southernmost basin in Angola, located just north of the Walvis Ridge, and developed as part of South Atlantic rifting in the Cretaceous. It is characterised by syn-rift to sag continental/lacustrine facies and post-rift marine sediments, separated by Aptian evaporites. However, a continental environment is temporarily re-established in the Late Cretaceous, with deposition of spring mound carbonate complexes following a regional Santonian magmatic event and renewed extensional tectonism.

Late Cretaceous continental carbonates in the Namibe Basin are now exhumed and represent a very good analogue in order to better understand facies development and fluid circulation pathways in volcanically influenced settings, as geometric relationships between carbonate facies are perfectly preserved, along with variations in diagenetic overprint. Facies include sub-aerial spring mound complexes with silicified botryoidal vent fabrics passing laterally into travertine slope systems and water-lain deposits of bivalve-gastropod coquinas. Spring mound complexes can be tens of meters thick and they mostly occur along a rift-antithetic fault, delineating the plumbing system that was active at the time of deposition. In the specific, six vent-slope systems are observed along a fault transect of less than 1 km, extending up to 500 m away from the fault. Water-lain deposits can be found as near as few tens of meters from the fault, possibly suggesting they were deposited in pools between different mound complexes.

Microscopy shows that the carbonates underwent several diagenetic modifications mostly related to circulation of fluids during hydrothermal activity. Facies are pervasively dolomitised, with dolomite replacing the original matrix and precipitating as cement overgrowths. Silicification is significant in the vent areas, occurring as anhedral and chalcedony replacive mosaics and as large blocky crystals in pores. Multi-stage brecciation is mostly affecting the vent areas, with breccias being infilled by dolomite cement and silica. Clumped isotope temperatures of dolomite matrix between 30°C and 55°C and $\delta^{18}\text{O}_{\text{SMOW}}$ fluid compositions between -1.4 and +2.6 suggest a plumbing system characterised by infiltrated heated groundwaters with possible contributions from more saline fluids.

25 - BIOGEOCHEMICAL DRIVERS OF MODERN CARBONATE FIRM-GROUND FORMATION: YAS LAGOON, ABU DHABI

Hazel Vallack¹, Sarah E. Greene², Stephen W. Lokier³, Jens Holtvoeth⁴, Victoria A. Petryshyn⁵, Emily N. Junkins⁶, Bradley S. Stevenson⁶, Fiona Whitaker⁴

1: *School of Geographical Science, University of Bristol, Hazel.Vallack@bristol.ac.uk*

2: *School of Geography, Earth and Environmental Sciences, University of Birmingham, S.E.Greene@bham.ac.uk*

3: *School of Ocean Sciences, Bangor University, S.Lokier@bangor.ac.uk*

4: *School of Earth Sciences, University of Bristol, Fiona.Whitaker@bristol.ac.uk*

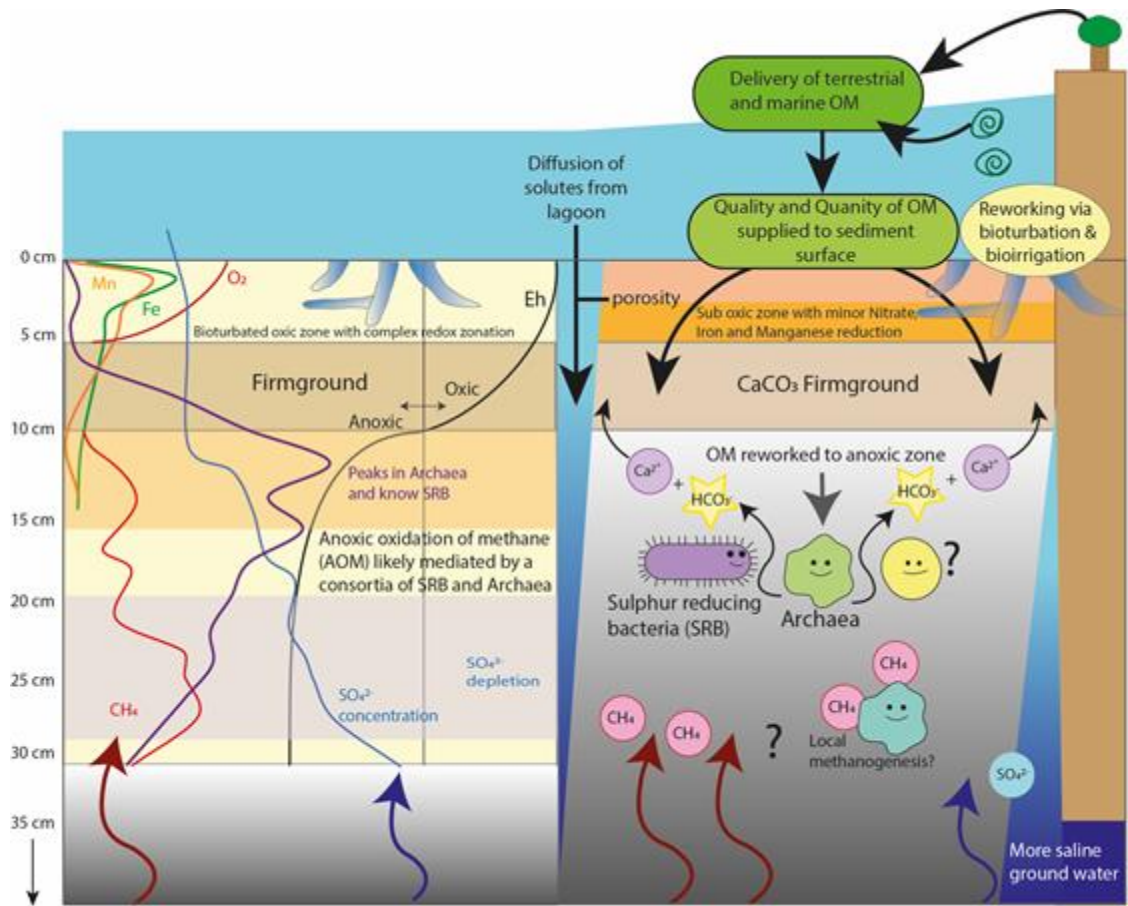
5: *Environmental Studies Program, University of Southern California, Los Angeles, Petryshy@usc.edu*

6: *Department of Microbiology and Plant Biology, University of Oklahoma, Bradley.stevenson@ou.edu*

Authigenic carbonates are common early-diagenetic features of sedimentary rocks and have been linked directly to the global carbon, sulphur, and iron cycles. The sea floor of the modern Arabian Gulf is characterised by extensive areas of recently-lithified carbonate sediments, with firm-grounds and hard-grounds cemented by acicular aragonite and high Mg-calcite cements. We investigated the environmental and geobiological controls of early cementation for one such firm-ground in a coastal lagoon in Abu Dhabi, which appears to be actively forming based on physical and chemical evidence.

Water depth in the semi-restricted intertidal lagoon ranges from 0 to 1 m, with surface water salinities of 46 - 47 ppt. Here a firm-ground occurs between 6 and 10 cm below the sediment-water interface, with grains surrounded by a relatively thin isopachous fringe of predominantly platy aragonite crystals. Porewaters at this location are marginally calcite supersaturated but undersaturated with respect to aragonite. The exception is immediately above and below the firm-ground, where marked increases in calcite and aragonite saturation states are associated with narrow (<2 cm) intervals of elevated porewater pH and low bicarbonate alkalinity. Sediments above the firm-ground were oxic, whilst those below were anoxic, indicating that the firm-ground formed an effective barrier to fluid exchange, possibly promoting the development of anaerobic conditions at depth that may further drive firm-ground cementation.

The breakdown of organic matter (OM) throughout the sediment column acts as the engine behind microbial respiratory pathways, the by-products of which produce chemical conditions that promote carbonate precipitation. The abundance and distribution of labile unsaturated lipids and bacterial lipid biomarkers show large differences in OM and microbial composition directly above and below the firm-ground and indicate the existence of microbial zonation within the sediment. Beneath the firm-ground, the porewaters are predominantly sulphate depleted and methane seems to diffuse upwards from the base of the profile (45 cm below the sediment surface) to the base of the firm-ground, which provides a permeability barrier. The 16S-rRNA signal of archaeal *Marine Benthic Group D* (MBG-D) increased in relative abundance immediately below the firm-ground in association with known sulphate reducing bacteria. Together they likely form a consortium involved in the anoxic oxidation of methane (AOM), which could potentially drive porewaters to aragonite and calcite supersaturation through the addition of bicarbonate, resulting in precipitation of carbonate cements and firm-ground formation.



26 KARST GEOBODY EXTRACTION THROUGH THE COMBINATION OF KARST CHARACTERISATION WORKFLOW AND PRINCIPAL COMPONENT ANALYSIS (PCA) IN CARBONATE FIELDS OF CENTRAL LUCONIA PROVINCE, SARAWAK.

S.F. Lim, D.A. Uli, A. Kumar, M.H.H. Mohammad, Z. Mohammad, Z.Z. Tuan Harith, A. Kolupaev and Y.F. Zainudain

The paper presents a method to quantify karst features present in the carbonate fields in Central Luconia Province, in terms of 3D geobody grids with distinct volumetric and reservoir properties. Several carbonate gas fields in Central Luconia province have experienced unpredicted high-water production and early water breakthrough during the production phase of the field. The assumption for the reasoning on the unpredicted water breakthrough issue for the fields was based on 2 reasons i.e. strong water aquifer from below the gas-water contact and high internal carbonate reservoir heterogeneity. Therefore, more robust reservoir characterisation practices need to be implemented to understand complex carbonate geological architecture; in order to mitigate, prevent, and optimise current carbonate gas fields production in Central Luconia itself. A comprehensive analysis was designed for this issue, which includes 3 components: Forward Stratigraphic Modelling (FSM), karst network characterisation and mapping, and uncertainty management. This paper itself discusses the mapping and picking of the karst grids using Principal Component Analysis (PCA) which is a type of Train Estimation Model. Previous carbonate geological models have always modelled karst features as property trends, based on seismic attribute analyses or through delineation of karst polygons which then overestimated or underestimated these karst features. These practices are not as effective because karst features in carbonate fields have a profound effect on the reservoir's flow units, for they will influence the internal geometry and architecture of the carbonate fields. On exposed carbonate platforms (isolated) that have only autogenic recharge like the ones in Central Luconia, the dominant karst landforms found will be closed depressions and caves. Before the mapping of the karst features were carried out, the karst features had to be analysed in terms of: possible locations of the karst features, formation of these features, and the lateral extension of these karst features. This strong understanding will then complement the karst characterisation workflow which includes (1) thorough observation for anomalies on seismic attribute volumes (2) observation on a flattened seismic cube (3) The Cylindrical and Overlapping technique, and lastly (4) Karst Geobody Extraction. After locating the lateral and vertical karsts network in the carbonate platforms, it is essential to be able to convert these karst features into 3D grids with a 3D-volume property. This was done by utilising the multi-seismic attribute analysis method which was the Principal Component Analysis (PCA). Therefore, the combination of the special characterisation workflow and PCA has allowed these karst features in the carbonate fields to be captured with a significant 3D grid volume, which in turn allowed the early-water breakthrough scenario to be better understood, better forecast of the influx of water from the aquifer below into the development wells of the field, and better placement of future infill wells.

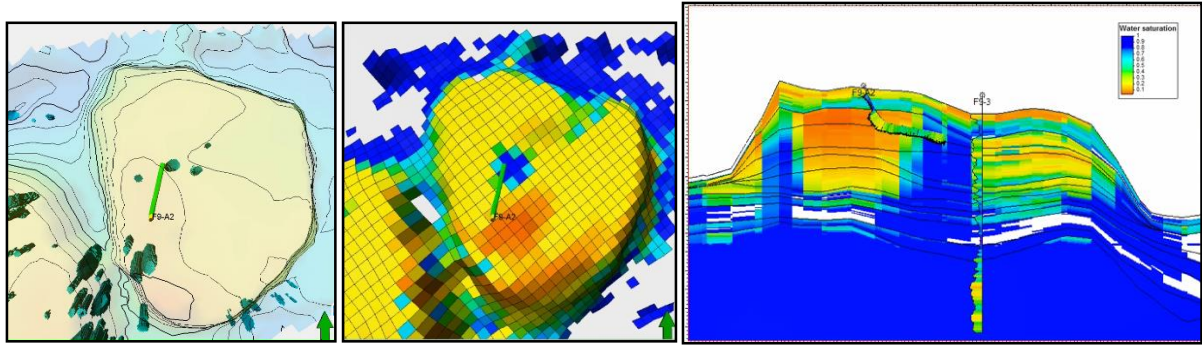


Figure: Vertical karst grids picked for one of the microplatforms in Field A. During the history matching of Well X-5, there was influx of water through the vertical karst feature which acted as a conduit/suction straw for the water below the GWC into the reservoir section

27 - DIFFERENTIAL DIAGENESIS CAUGHT IN THE ACT: LITHOLOGICAL DEPENDENCE OF *HYDROBIA* (GASTROPOD) PRESERVATION IN MONOSPECIFIC DEPOSITS FROM THE MIOCENE MAINZ-BASIN (SW-GERMANY)

Theresa Nohl¹, Jannick Wetterich¹, Axel Munnecke¹

¹Friedrich-Alexander-Universität Erlangen-Nürnberg, Geozentrum Nordbayern, Loewenichstr. 28, 91054 Erlangen, theresa.nohl@fau.de

The origin of limestone-marl alternations (LMA) is a lively debated topic in carbonate sedimentology. Regardless of the discussion on the causes of the rhythmicity it is known that the limestones have been lithified early, and that the cement carbonate is derived from dissolution processes in the adjacent marls. It is debated, however, whether pressure dissolution of calcite or selective aragonite dissolution (differential diagenesis) is the major process. This question is difficult to answer because aragonite is usually not preserved, and thus its dissolution hard to prove. The Miocene brackish-water deposits (Rüssingen Formation) from the Mainz-Weisenau quarry in central Germany studied here might offer an opportunity to fill in this gap in knowledge because they still contain significant amounts of aragonite, which means they can be considered diagenetically immature. These carbonates are developed as horizontal beds of moderately to poorly lithified monospecific sands of aragonitic *Hydrobia* snails, i.e. they reflect an alternation of lithified and non-lithified beds which resemble classical limestone-marl alternations. These monospecific deposits reflect times of little to no changes in sediment input and allow to study and compare the preservation of *Hydrobia* in the two lithologies, and thus to gauge the diagenetic process forming LMA and its influence on aragonite loss.

XRD and RFA analyses revealed high CaCO₃ contents (92% in average) throughout the measured section without any significant differences between lithified (limestones) and unlithified (marl) layers. Analyses of the carbonate phases, however, revealed a high amount of aragonite and a low amount of calcite in the marls, and the opposite in limestones, where calcite is the main carbonate phase. These differences in aragonite to calcite ratio (A/C ratio) fit the model of differential diagenesis. According to this model aragonite is dissolved, transported along geochemical gradients, and then re-precipitated as calcite cement, thereby lithifying the later-on limestone beds. The different preservation of the aragonitic fossils is documented by observations of stained thin sections. Although the unlithified layers have experienced significant loss of aragonite by dissolution their relative amount of aragonite is higher than in the lithified layers because the dissolved aragonite precipitated as calcite cements in the limestones, shifting the A/C ratio. It is concluded, that although the investigated rhythmic carbonates are no classical (micritic) limestone-marl alternations, they obviously have experienced the same type of differential diagenesis.

28 - INFLUENCE OF LONG TERM EXPOSURE SURFACES ON THE COMPARTIMENTALIZATION AND DISTRIBUTION OF MICROPOROSITY IN SHALLOW-WATER CARBONATES: THE BARREMIAN-APTIAN PLATFORM FROM SE FRANCE

Hugues BITAULT^{a,c}, Philippe LÉONIDE^a, François FOURNIER^a, Cathy HOLLIS^c, Matthieu ROUSSEAU^b & Jérôme HENNUY^b

^a Aix-Marseille Université, CNRS, IRD, Cerege, Um 34, 3 Place Victor Hugo (Case 67), 13331 Marseille Cedex 03, France; Hugues.Bitault@manchester.ac.uk

^b TOTAL S.A., Centre Scientifique & Technique Jean Féger, Avenue Larribau, 64018 Pau, France.

^c The University of Manchester, Williamson Building, Oxford Road Manchester M13 9PL, United Kingdom

ABSTRACT

The development and the distribution of microporosity in carbonate rocks below long term exposure surfaces, result from a complex interaction between early marine diagenesis, stratigraphic stacking pattern, early structuration of the reservoir and fluid circulation during long-term exposure events. A High-resolution characterization of the vertical and lateral evolution of porosity and permeability attributes coupled with petrographical (sediment texture, facies) and diagenetic analysis (cement stratigraphy, and isotope geochemistry) has been performed on 100 carbonate samples on a kilometer-scale outcrop from the Urgonian limestone (Late Barremian/Early Aptian) to assess the impact of subaerial exposure diagenesis on underlying carbonate sediments. These analysis revealed that early mixed (meteoric & marine) cementation during repeated subaerial exposures in autocyclic, peritidal parasequences led to the occlusion of intergranular and intragranular pore space (=tight limestones). In contrast shallow water carbonate sediments that were not exposed during repeated subaerial exposure events, have kept a significant fraction of the intergranular macroporosity during burial. Such porous carbonates were subject to micrite neomorphism caused by meteoric shallow burial diagenesis during the Durancian subaerial exposure event (Albian-earliest Cenomanian). Such a diagenetic evolution resulted in a significant development of intragranular microporosity. However, an intricate structuration of the reservoir system due to normal fault movements preserved the shallow water carbonate from meteoric diagenesis in the hangingwall part preventing the formation of intragranular microporosity. Such variation in intragranular microporosity is also confirmed by the variation of micritic microfabrics through the reservoir system at a kilometer-scale.

29 - PETROPHYSICAL AND ACOUSTIC PROPERTIES OF TWO MIDDLE EAST RESERVOIRS; A COMPARISON BETWEEN CALCITIC AND ARAGONITIC SEA DEPOSITS

Moaz Salih¹, John J.G. Reijmer¹, Luis A. González¹, and Ammar El-Husseiny¹

¹: College of Petroleum Engineering & Geosciences - KFUPM, Dhahran, Saudi Arabia

A total of 84 carbonate samples covering two major reservoir formations from Saudi Arabia, the Permian-Triassic Khuff Formation, and the Late Jurassic Hanifa Formation were analysed, to document variations in the petrophysical properties and the associated acoustic velocity. The sediments of the Khuff Formation form the largest gas reservoir in the world, whereas the Hanifa sediments are a source rock in its lower part (Hawtah Member) and an oil reservoir in the upper part (Ulayyah Member). Compressional velocity was measured using PROCEQ ultrasonic pulse measurement tool at ambient pressure. The porosity values of the Khuff Formation sediments range from 2.02% to 36.12%, with an average of 4.35 %, and the permeability ranges from 0.001mD to 8.84mD, with an average of 0.38 mD. The porosity values of the Hanifa Formation sediments range from 0.77 -19.72% with an average of 10.62 %, while the permeability varies from 0.0001 to 1.91mD, with an average of 0.30 mD. The acoustic velocity of the Khuff Formation sediments ranges from 1.98 to 5.54 km/sec with an average of 4.35 km/sec, whereas the acoustic velocity for the Hanifa Formation sediments are higher ranging from 3.4 - 6.3 km/sec with an average of 4.7 km/sec. The velocity-porosity trend line of the Hanifa Formation sediments is higher than Khuff Formation sediments, which could be attributed to the pore type effect. Porosity in the Hanifa Formation sediments is dominated by intra-particle and framework porosity, whereas in the Khuff Formation sediments porosity is dominated by microporosity and interparticle porosity. At high porosity values (> 30%), the Khuff samples have a higher velocity values due to the dominance of oomoldic pores within sediment framework with a high stiffness. The mineralogy of the two groups (Khuff and Hanifa formations) is almost similar, with calcite content that is higher than 90%. However, quartz- rich samples have a lower velocity values relative to their calcitic counterparts. In addition, Hanifa Formation sediments were deposited in a calcitic sea during the Late Jurassic and most of the Hanifa components were originally calcitic. However, Khuff formation sediments were deposited in an aragonitic sea during the Late Permian and were originally aragonite that was neomorphosed to calcite. Neomorphism played a major role in decreasing the velocity by adding more crystals and increasing crystal interfaces. In conclusion, the sediment composition, their original mineralogy and pore structure distribution, and subsequent modification by diagenetic processes influenced the acoustic velocity development through time.

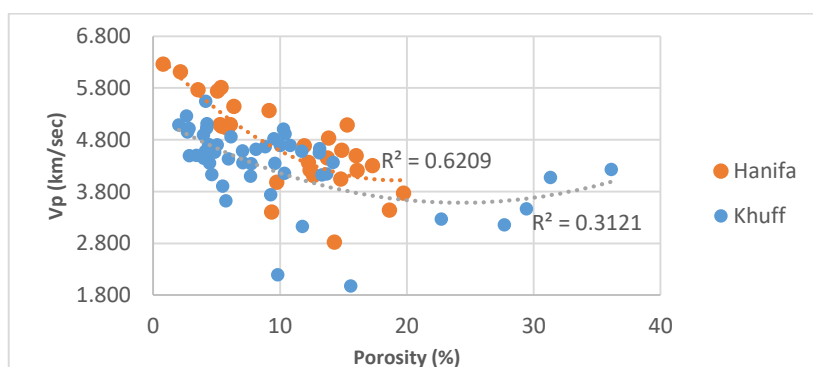


Figure 1. Compressional velocity-porosity trend of Khuff and Hanifa formations, showing higher velocity values of the Hanifa samples.

30- HOT AND LATE: CLUMPED ISOTOPES IN MIDDLE JURASSIC CALCITE-CEMENTED CONCRETIONS FROM SKYE

Richmal Paxton, Julian Andrews, Paul Dennis, Alina Marca

School of Environmental Science, University of East Anglia, Norwich, NR4 7TJ

Email: r.paxton@uea.ac.uk

Spectacular, decimetre-scale, calcite-cemented concretions hosted in the Middle Jurassic Valtos Sandstone Formation of Skye should record, through their geochemistry, the origin of pore waters from which they grew. On the basis of stable isotope data and assumptions about either water compositions or temperatures, these cements have long been thought to form from meteoric water, and various lines of evidence suggested the pore waters were of Middle to Upper Jurassic age (Wilkinson 1993). This said, the concretions from Valtos in Trotternish had some unusually negative $\delta^{18}\text{O}_{\text{calcite}}$ compositions that were difficult to interpret.

Recent availability of clumped isotope measurements mean that previous assumptions about palaeotemperatures can now be tested. Furthermore, knowing both temperature (from clumped isotopes) and $\delta^{18}\text{O}_{\text{calcite}}$ it is also possible to calculate pore fluid compositions.

Measurements of a concretion previously studied by Wilkinson (1993) show centre to edge temperatures trending from 50°C to 80°C. Using these temperatures and the measured $\delta^{18}\text{O}_{\text{calcite}}$ values, pore water $\delta^{18}\text{O}$ were calculated. The pore waters show a centre to edge evolution from -12‰ to +3‰VSMOW. The starting composition of -12‰VSMOW is highly significant; it is incompatible with Jurassic meteoric water composition, which is unlikely to have been <-6‰VSMOW (Hudson & Andrews, 1987). Instead, -12‰VSMOW is exactly the composition of Hebridean Palaeocene meteoric water as demonstrated by a number of classic studies. Concretion growth thus began in the Palaeocene.

The calculated temperatures of cement formation are higher than previously assumed, suggesting either deeper burial (or higher geotherm) or warmer pore waters. Results from similar Valtos Sandstone concretions from Eigg support these high temperatures. It is possible that Palaeocene pore waters were heated as the Jurassic sandstones underlie basaltic lavas and sills of the Hebridean Igneous Province.

Following Palaeocene initiation of concretion growth, the evolution in pore water composition from -12‰ to +3‰VSMOW suggests a water–rock interaction signal. It is not yet clear whether this implies interaction with older basinal mudrocks or with overlying Tertiary (Palaeocene) lavas.

The new clumped isotope data fundamentally alters the interpretation of sandstone concretion growth in this region, showing that the cements formed much later and at higher temperatures than previously assumed. The study exemplifies the power of the carbonate clumped isotope paleothermometer in investigating burial cementation and diagenesis in both sandstones and limestones.

References

- Hudson, J.D. & Andrews, J.E., 1987. The diagenesis of the Great Estuarine Group, Middle Jurassic, Inner Hebrides, Scotland. *Geological Society of London, Special Publication*, **36**, 259-276.
- Wilkinson, W., 1993. Concretions of the Valtos Formation of Skye: geochemical indicators of palaeo-hydrology. *Journal of the Geological Society of London*, **150**, 57-66.

31 - HYDROBRECCIAS, ZEBRA DOLOMITE, AND CRACK-SEAL TEXTURES; IMPLICATIONS FOR THE EMPLACEMENT OF FAULT-CONTROLLED DOLOMITE

C.A. McCormick¹, C. Hollis¹, E.H. Rutter¹, H. Corlett².

1. Department of Earth and Environmental Sciences, The University of Manchester, Manchester, UK

2. Department of Physical Sciences, MacEwan University, Edmonton, CA

Although dolomite has been the subject of extensive research, uncertainty persists regarding its formation, particularly when formed through fault-controlled dolomitization. Certain diagnostic rock textures found in these successions, such as hydrobreccias and zebra textures, can be classified as diagenetic facies with a distinct relationship between fault proximity and the precursor limestone texture. Although these textures provide invaluable information regarding the spatial and temporal evolution of diagenetic fluids in a basin, they have not been studied in depth and are inappropriately amalgamated as a single step in the overall paragenetic sequence of the succession. Zebra textures, for example, consist of alternating, centimeter-scale, parallel-to-sigmoidal, light/dark bands that are found in dolomite of various ages and tectonic settings. Numerous conceptual models have been proposed to explain the formation of zebra textures^{1,2}, each of which typically suggest that the dark bands formed by the replacement of the carbonate host rock and that the light bands are elongate, cement-filled, cavities. There is, however, contention regarding whether these cavities are passively cemented¹ or tectonically induced². Of the few studies that have been completed, a comprehensive petrographic, geochemical, and geomechanical characterization has not yet been conducted.

This study focuses on exposures of fault-controlled dolomite in the Middle Cambrian Cathedral Formation and the overlying the Middle Cambrian Eldon Formation in Alberta, Canada. These outcrops, which exhibit a wide array of rock textures, are ideally located to describe and interpret dolomitization and dolomite cementation over a relatively short distance. Samples from these exposures will be fully characterized petrographically (transmitted light, cathodoluminescence, and scanning electron microscopy, x-ray diffraction) and geochemically (trace elements, stable isotopes, clumped isotopes, fluid inclusions). Preliminary petrographic analysis of the cement phase in zebra dolomite (Fig. A) has revealed that crystals are syntaxial built by a succession of crack-seal increments (Fig. B; C). Crack-seal textures, which arise due to the competition between the rate of cement precipitation and fracture opening³, suggest that these cavities were not passively cemented and that the basin was tectonically active during dolomite emplacement. The results of this study are supported by tensional rock deformation experiments that demonstrate the requirement for a local hardening mechanism to propagate multiple, closely spaced fractures.

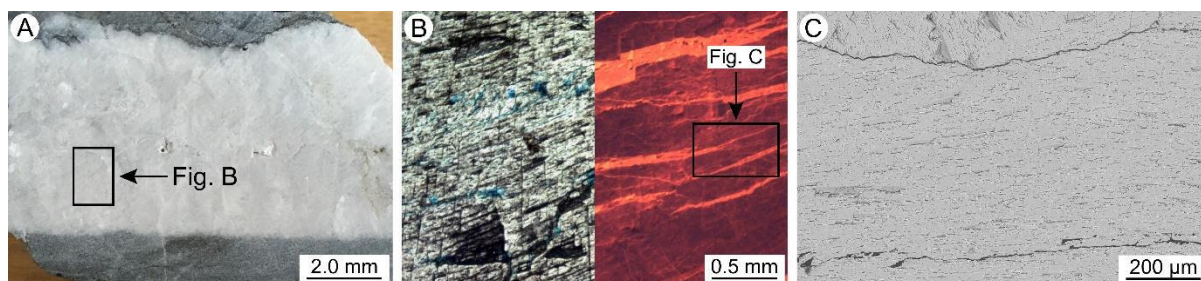


Fig. A) Cathedral Formation zebra dolomite hand specimen, B) Plane polarized light photomicrograph (left), cathodoluminescence photomicrograph (right), and C) Scanning electron photomicrograph.

References

1. Morrow, D.W., 2014. Zebra and boxwork fabrics in hydr. dolomites of northern Canada: Indicators for dilational fracturing, dissolution or in situ replacement? *Sedimentology*, **61(4)**, 915-951.
2. Vandeginste, V., Swennen, R., Gleeson, S.A., Ellam, R.M., Osadetz, K., Roure, F., 2005. Zebra dolo. as a result of focused fluid flow in the Rocky Mountains, Canada. *Sedimentology*, **52(5)**, 1067-1095.
3. Ramsay, J.G., 1980. The crack–seal mechanism of rock deformation. *Nature*, **284(5752)**, 135-139.

32 - THE IMPACT OF HYDROCARBON EMPLACEMENT ON CEMENTATION IN CARBONATE RESERVOIRS

Stephen Gundu¹, Cees van der Land¹, Sanem Acikilan¹, Tannaz Pak², Shannon Flynn,¹ Laura Galluccio³

1. School of Natural and Environmental science, Newcastle university.UK.

2. Department of Petroleum Engineering, Teesside University.UK.

3. Badley Ashton, Lincolnshire.Uk

The role of hydrocarbon emplacement on inhibiting cementation and preserving reservoir quality has been highly debatable over the years. Few studies have highlighted the dynamics of cementation in the presence of oil emplacement, establishing the conditions and factors that make oil emplacement to inhibit cementation and thus, preserving porosity and permeability. But these studies remain quite uncertain, because they have largely been qualitative and based on petrographic analysis of the final reservoir rock properties. Paleo-fluid rock interaction and the exact paleo-fluid geochemistry has not been properly reconstructed and matched with porosity-permeability preservation in the reservoir.

Here, we demonstrate the nature and geochemical conditions necessary to induce calcite cementation in porous media and how hydrocarbon presence can affect these conditions. To do this we have used an experimental diagenesis approach, that involves the flowing of a supersaturated brine solution with respect to calcite, through a limestone of different wettability with varying levels of hydrocarbon saturations. Initial experiments have demonstrated the rate of precipitation of calcite from brine and its inhibition across varying conditions at room temperature, using SEM analysis. This study is the first step to producing an empirical and quantitative evidence for the impact of hydrocarbon emplacement on the cementation process at the pore scale level, the next phase is to investigate and confirm the dynamics of this cementation in porous media, using micro-computer tomography, which will enable microscale 3D imaging of the pore system.

33 - DIAGENETIC EVOLUTION OF JURASSIC PLATFORM CARBONATES ALONG THE NE ATLANTIC MARGIN

Nawwar Al-Sinawi¹, Cathy Hollis¹, Stefan Schröder¹, Jonathan Redfern¹

¹*University of Manchester, School of Natural Sciences, North Africa Research Group, Oxford road, Manchester, M13 9PL, UK.*

***Corresponding Author:** Nawwar.al-sinawi@manchester.ac.uk

Diagenesis of Jurassic carbonate platforms in the Essaouira-Agadir Basin (EAB) are complex due to multiple phases of dolomitization. This study aims to map the distribution of the dolomite and reconstruct its formation within the Sinemurian to Pliensbachian and Oxfordian platform carbonates in the Western High Atlas (WHA) of Morocco. Excellent outcrop exposures allowed this to be done in the context of the entire diagenetic evolution in the EAB. Reactive fluids include seawater, evaporative fluids released during diapiric growth, crustal fluids released during basin inversion, hydrocarbon and meteoric fluids during exposure and karstification.

Dolomitization is the most significant diagenetic process that affected Jurassic carbonates that grew on the passive margin in the WHA, which is the focus of this study. These carbonates overlay Triassic siliciclastic sediments, salts and the Central Atlantic Magmatic Province basalts. Integrated outcrop observations, petrographic and geochemical analysis allowed evaluation of the dolostone distribution and geometry to characterize the controls, origins and timing of dolomitization across the basin.

Dolomitization was initiated on all platforms by reflux of seawater forming fabric preserving dolomites dominated by euhedral to subhedral crystal texture, oxygen and carbon isotopes similar or close to typical Jurassic marine carbonates and record <50°C dolomitizing fluid temperature. This was followed by recrystallization by anhedral and saddle dolomite around faults and fractures. These dolomites are relatively depleted isotopically, compared to Jurassic marine carbonates with dolomitizing fluids temperatures that are up to 134°C. The last diagenetic event is characterized by meteoric fluid percolation through the strata during uplift caused by the Alpine compression, accompanied by hydrocarbon migration. Jurassic dolomitized carbonates offer important reservoirs along the Central Atlantic Margin, but a key challenge is predicting porosity generation and preservation. This study provides an insight into the variability, spatial and temporal distribution and controls, aiding predictability in the subsurface.

Keywords: Dolomitization, Jurassic carbonates, marine dolomites, Triassic salts, hydrothermal dolomites, Morocco

34 - APPLICATION OF CLUMPED ISOTOPE PALAEO THERMOMETRY TO RECONSTRUCT THERMAL EVOLUTION OF RECRYSTALLISED CALCITE IN FINE-GRAINED MICRITES

Sarah Robinson¹ Cédric M. John¹ Annabel Dale² Mark Osborne²

¹Imperial College London, UK ²BP Exploration & Production, Sunbury on Thames, UK

Fine-grained micritic sediments are an under researched area, especially focusing on the inorganic content within these micritic sediments. This study is focusing on understanding how recrystallisation of carbonate is recorded during burial of fine-grained micrites. Previous studies investigating recrystallisation in fine-grained dolomite have demonstrated that at both shallow burial depths (<1km) and low temperatures (<40°C) carbonate clumped isotopes are altered and no longer represent the environment of deposition. However, now capture the temperatures present during burial. Using a combination of clumped isotope palaeothermometry, pyrolysis and SEM/EDS imaging this study will investigate whether in fine-grained calcitic micrites a similar isotopic alteration as fine-grained early dolomites is observed. This is an important as we need to understand carbonate clumped isotopes in fine grained calcites in order to understand whether measured temperatures are representative of temperatures reached during burial. This impacts whether we can use the carbonate clumped isotope method as a proxy in fine grained calcites to reconstruct the thermal evolution of a formation and burial diagenetic processes.

Analysis has been done on 18 samples collected from outcrops located on the west of the Eagle Ford Shale outcrop belt, Texas. The Eagle Ford is an ideal study location as it contains abundant fine-grained carbonate mixed with clastic material. The burial depth (<2km) and temperature reached (immature, <70 degrees) are understood through using organic proxies obtained from pyrolysis in this study, giving this study a reasonable calibration for temperatures obtained through clumped isotope palaeothermometry. Pyrolysis has indicated that all samples have a Tmax value of less than 436°C, indicating samples have not reached higher than 70°C for a sufficient amount of time to mature the organic matter present. Clumped isotope analysis shows variability in both measured clumped isotope temperatures ($T(\Delta_{47 \text{ calcite}})$, 35 to 100 °C) and calculated water oxygen isotope composition ($\delta^{18}\text{O}_{\text{vsnow}}$, -1.93 to 6.96 ‰). The results show some samples to have higher temperatures than expected based on Tmax obtained from the organic matter. This indicates that thermal evolution of calcite recrystallisation may differ from that of organic matter transformation. This difference likely originates from differing kinetics that exist for the two reactions. Organic matter transformation depends on both temperature and time and this is what the measurement Tmax demonstrates, whereas carbonate recrystallisation can occur instantaneously and depends on temperature and the fluid present. The clumped calculated temperature represents this as the clumping of heavy isotopes is temperature dependent. A correlation exists between $T(\Delta_{47 \text{ calcite}})$ and $\delta^{18}\text{O}_{\text{vsnow}}$; the higher $T(\Delta_{47 \text{ calcite}})$, the higher $\delta^{18}\text{O}_{\text{vsnow}}$. This correlation is interpreted to be evidence of burial recrystallisation via dissolution/re-precipitation within a closed system, therefore with minimal to no change in the $\delta^{18}\text{O}_{\text{calcite}}$. We suggest that even with the large range of measured $T(\Delta_{47 \text{ calcite}})$, these variations could be a result of recrystallisation via dissolution/re-precipitation during burial and therefore representative of maximum burial temperatures, which are not recorded by the organic temperature proxies.