Distribution, fabrics and mineralization of microbialites in Great Salt Lake (Utah, USA)

Pace, A.[1, 2], Bouton, A.[3], Bourillot, R.[1], Vennin, E.[3], Visscher, P.T.[4], Dupraz, C.[4], Thomazo, C.[3], Galaup, S.[1], Leleu, S.[1], Kwasniewski, A.[5], Pigot, L.[1], Franceschi, M.[1]

[1] EA 4592 Géoressources et Environnement, ENSEGID, 1 allée Daguin 33607 Pessac Cedex, France – aurelie.pace@ensegid.fr
[2] Université Bordeaux 3, Domaine Universitaire, 33607 Pessac, France
[3] Laboratoire Biogéosciences UMR uB/CNRS 6282 Université de Bourgogne, 6 boulevard Gabriel, 21000 Dijon, France
[4] Department of Marine Sciences, Center for Integrative Geosciences, University of Connecticut, 1080 Shennecossett Road, Groton, CT 06340, USA
[5] Total, Avenue Larribau, 64018 Pau, France

Great Salt Lake (GSL) is located in the Basin and Range province of Utah (USA). Its average surface is 4480 Km^2 and maximum depth of is about 15m. It is a partly rainfed endorheic hypersaline lake (average salinity: 140g/L). Due to the high salinity, little or no predators are present in the lake, favoring the development of microbialites that cover the margin of the lake.

This work aims at establishing the distribution, fabrics and mineralization processes of recent and modern microbialites on the western margin of Antelope Island. Stromatolites and thrombolites are used here as sedimentary archives to decipher the complex changes of the GSL chemistry over the last centuries.

We established a detailed map of the carbonate, detrital and microbial deposits. The distribution of microbialites and their morphology has been studied along lakeshore to center transects, showing a contrasting spatial distribution in bay versus headland. Sedimentary dynamics, the nature of the substrate and syn-sedimentary tectonics seem to control microbialite distribution and morphology. Microfabrics show a great diversity, some microbialites being essentially built by microbial-mediated carbonate precipitation, while other show the predominance of trapping and binding processes.

The nature and composition of the microbial carbonates have been determined through polarizing, CL, reflected fluorescence microscopy, XRD and isotope geochemistry in order to investigate the preservation of environmental signals in microbialites. Permeability and porosimetry coupled with CT scan have been used to compare fossil and modern microbialites pore networks and structures to better understand the different steps of the diagenesis. Cryo-SEM analyzes have been done on the living microbial mat samples permitting to show microcrystals in the organic matrix, which indicates a probable ongoing mineralization. In the mat, mineralization zones seem to coincide with maximal sulfate reduction hotspots.

These results shed a new light on the understanding of the GSL sedimentary system.

Freshwater and marine ooids: a common microbial origin?

Pacton, M.[1, 2], Grossi, V.[1], Ariztegui, D.[3], Mutti, M.[4], Adam, P.[5], Schaeffer, P.[5], Rollion-Bard, C.[6], Vasconcelos, C.[2]

[1] Laboratoire de Géologie de Lyon, Université Claude Bernard Lyon 1, France - muriel.pacton@univ-lyon1.fr
[2] Geological Institute, ETH-Zürich, Switzerland
[3] Section of Earth & Environmental Sciences, University of Geneva, Switzerland
[4] Institut für Erd- und Umweltwissenschaften, Universität Potsdam, Germany
[5] Laboratoire de Biogéochimie Moléculaire, UMR 7177 CNRS, Université de Strasbourg, France
[6] Institut de Physique du Globe de Paris, UMR 7154, France

Although ooids are one of the common constituents of ancient carbonate rocks, the role that microbial communities may or may not play in their formation remains controversial. Ooids are typically 2 mm (or less) in diameter and accrete around a nucleating fragment (quartz or bioclast) in agitated environments. They display different mineralogies such as aragonite or low-Mg calcite depending on the water chemistry, i.e., in lacustrine or marine settings. Although an abiotic origin of ooids has been advanced, recent studies have demonstrated a biological role in the formation of ooids in freshwater environments. Novel investigations based on molecular biology and lipid biomarkers further support a potential role of microbes in the formation of marine ooids. However, while photosynthetic microbes have been shown to mediate the formation of the entire cortex of ooids in Lake Geneva, there is a lack of in-depth studies to elucidate the precise role of microbes in carbonate precipitation in marine ooids.

The present study focuses on the comparison between freshwater and marine ooids based on the evidence of microbial activity in relation to carbonate precipitation. Different ooid samples were collected in the Bahamas, Abu Dhabi and Lake Geneva and analysed using microscopic (scanning electron microscopy), spectrometric (in-situ $\delta^{13}C$ measurements) and lipid biomarkers (distribution and compound specific carbon isotopic composition) approaches.

Preliminary results show that, in both marine and freshwater ooids, the inner carbonate cortex displays a light C-isotopic signature and is associated with low Mg-calcite. In the case of aragonite ooids, low Mg-calcite layers include microbial extracellular polymeric substances (EPS) and are intercalated within aragonite only in the inner part of the cortex, while the outer part is dominated by aragonite and microborings. The lipid biomarker (hydrocarbons and fatty acids) distributions and stable carbon isotopic compositions are consistent with mixed inputs from bacteria, terrestrial plants and algae to ooids. The highly similar lipid composition of freshwater and marine ooids strongly support the hypothesis that ooid formation is mediated by a specific microbial community.

Exploring past microbial activity in high altitude lake sediments (lake Son Kul, Central Asia): a novel approach of sedimentary facies analysis

Pacton, M.[1], Sorrel, P.[1], Bevillard, B.[1], Zacaï, A.[1], Vinçon-Laugier, A.[1], Oberhänsli, H.[2, 3]

[1] Laboratoire de Géologie de Lyon, Université Claude Bernard-Lyon 1, France - muriel.pacton@univ-lyon1.fr
[2] Helmholtz-Centre Potsdam, German Geoscience Research Centre (GFZ), Potsdam, Germany
[3] Museum für Naturkunde, Leibnitz-Institute Berlin (Mineralogy), Berlin, Germany

The fabric of sedimentary rocks in lacustrine archives usually contains long and continuous proxy records of biological, chemical and physical parameters that can be used to study past environmental and climatic variability. Here we propose a new approach of sedimentary facies analysis based on a coupled geomicrobiological and sedimentological study using high-resolution microscopical techniques (petrographic microscopy, scanning electron microscopy, transmission electron microscopy and laser scanning confocal microscopy) in combination with mineralogical (X-Ray) analyses. We test the applicability of this approach on sediments from Lake Son Kul, a high alpine lake in central Tien Shan (Kyrgyzstan, Central Asia). Preliminary studies on lake Son Kul revealed the sequence of palaeoenvironmental change during the last ca. 8000 years based on palynological and palaeolimnological approaches.

This interdisciplinary study sheds a new light on the mineral fabric and microbial communities observed down to the nanoscale in lake sediments. Results indicate that lake Son Kul shares similarities with Antarctic lakes by aragonite predominance, which is here mainly of primary origin and driven by biological activity in the epilimnion. In contrast, other carbonates are formed during early diagenesis and triggered by sulphate-reducing bacteria and possibly methanotrophic archaea. Low lake levels are inferred between ca. 7000 and 5000 cal. BP, as indicated by the presence of interspersed aragonite deposits and microbial mat structures, in which anaerobic oxidation of methane played an important role and mediated the formation of a new morphotype of aragonite (i.e., spherulite-like precursor). Such microbial mat structures enhanced the preservation of viral relics, which have not been reported in Holocene lacustrine sediments yet.

This study emphasizes the relevance of investigating microbe-mineral interactions to decipher biotic and abiotic processes in Quaternary sediments by complementing traditional facies sedimentology tools. Hence this approach can be used successfully for a comprehensive description of the fabric of laminated lake sediments and opens new perspectives for the search of microbial and viral biosignatures in lacustrine archives.

Detrital fingerprints of arc-continent collision: contrasting signatures of accretion and unroofing in modern sands from Taiwan

Padoan, M.[1], Resentini, A.[1], Vezzoli, G.[1], Garzanti, E.[1], Castelltort, S.[2], Tien-Shun Lin, A.[3]

[1] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Piazza della Scienza 4, 20126, Milano, Italy - marta.padoan@unimib.it
[2] Department of Earth Sciences, University of Geneva, Geneva, Switzerland
[3] Department of Earth Sciences, National Central University, Jungli, Taiwan

Over a hundred modern sand samples from all major rivers and several beaches were collected all around the island of Taiwan, representing the archetypal tectonic product of arc-continent collision. The Taiwan orogen is a doubly-vergent wedge generated by the eastward subduction and collision of the Chinese passive margin with the Luzon volcanic arc (Byrne et al., 2011). From west to east, different tectono-stratigraphic units are exposed, each characterized by its own detrital signature:

- the Western Foothills, a fold-and-thrust belt consisting of accreted Oligo-Miocene sediments originally belonging to the Chinese margin, sheds litho-quartzose sedimentaclastic detritus, with very poor heavy mineral assemblages including zircon, tourmaline, rutile, epidote and garnet;
- the Slate Belt, made of very-low grade metapelitic rocks, sheds quartzo-lithic metasedimentaclastic detritus with very poor zircon-tourmaline assemblages;
- the polymetamorphic Tananao Complex, including marbles, schists and gneisses, sheds quartzo-lithic metamorphiclastic detritus with moderately rich epidote-hornblende suites;
- the Coastal Range includes Neogene volcanic rocks representing the remnants of the collided Luzon and syn-collisional Plio-Pleistocene siliciclastic rocks, shedding, respectively, feldspatho-lithic volcaniclastic sands with rich clinopyroxene-hypersthene suites and quartzo-lithic sands with cellular serpentinite and poor suites including hypersthene, epidote, clinopyroxene, volcanic hornblende and rare Cr-spinel.

Our provenance analysis based on numerous compositional parameters, including the Metamorphic Index (i.e., average metamorphic rank of rock fragments; Garzanti and Vezzoli, 2003) supports and extends to the present time the conclusions reached by previous petrographic and mineralogical studies of Neogene sedimentary rocks. In the western pro-side of the orogen, progressive accretion and recycling of accreted passive-margin strata determines an ongoing dilution of metamorphic detritus by sedimentary detritus shed from the frontal range (Nagel et al., 2014). Instead, progressive unroofing of the medium-grade axial roots of the orogen is documented along the eastern retro-side of the orogen (Dorsey, 1988).

Quantitative mineralogical analysis of modern sands highlights efficiently the interplay between tectonic and surface processes, as well as erosion and exhumation patterns in different parts of Taiwan. This technique provides independent information comparable to the results of thermochronological analysis.

External geometry of gravity-flow deposits in Songliao Basin, China: classification, controlling factors and hydrocarbon implication

Pan, S.[1], Liu, H.[1], Wei, P.[1], Liang, S.[1], Liu, C.[1]

[1] Research Institute of Petroleum Exploration & Development-Northwest, Petrochina, 730020, Lanzhou, China - ltpan@126.com

External geometry of submarine gravity-flow deposits are widely described and discussed in the literatures. Growth fault, slope gradient, salt movement, mud volcano, gully or canyon system, regional tectonics settings, geomorphology of the slope and bottom current profoundly influenced sedimentary process, discharged places, run-out distance, internal architecture and external geometry of gravity-flow deposits. As a consequence, the sedimentary system does not exhibit classic fan-like geometry.

Slope break of lacustrine basin is different from continent slope in term of framework, microfacies, sandbody, scale and shape, but slope break is an ideal discharge place for gravity depositions. In recent years gravity deposition has become one of the major targets for reserve growth in China nonmarine basins. However, little research has been pay attention to external geometry and its controlling factors of gravity-flow deposits in lacustrine setting. The main purpose of this study is to show that gravity-flow deposits in slope break of Qingshankou Formation, the Songliao Basin (SLB), exhibit several different external geometry. Another purpose is to emphasize that external geometry are influenced by local and external factors such as tectonic setting, climatic or lake-level changes, basin-floor geomorphology and bottom current. External and local controlling factors on slope break interplay to cause different geometry.

Applied principle and technique of seismic geomorphology, large scale lacustrine gravity-flow deposits are identified within lacustrine mudstone of Qingshankou Formation in the central depression of SLB. Poststack 3-D seismic data used in this study have high quality in terms of data processing and frequency contents. Eight key surfaces had been mapped using the seismic data volume. These key surfaces included qn1 bottom, qn1top, qn2 top and qn3 top, as well as four reflectors of foreset sand bodies in the Qingshankou Formation. External geometry of gravity-flow deposits was achieved by seismic amplitude extractions.

Three-dimensional seismic geomorphology provides a deterministic means of mapping the geometry of gravity-flow deposits. Based on the seismic geomorphology study of external geometry, three distinct categories of gravity-flow deposits are identified: (1) Channel-fan, (2)Fan-like and (3) Non-fan-like complexes. Furthermore, fan-like systems can be divided into three subcategories, including isolated fan, mother-son fan and stacked fan. Non-fan-like complexes can be divided into three subcategories: fault-controlled pit, fault-controlled valley and strip-like systems.

The three-dimensional seismic data permits detailed study and mapping of the various external geometry of gravity-flow deposits. Growth fault, slope gully, slope gradient, basin-floor geomorphology and bottom current greatly influenced sedimentary process and external geometry of gravity-flow deposits in SLB. Gravity-flow deposits in SLB exhibit classic fan-like geometry and some special (non-fan-like) external geometry, and applying of conventional submarine fan models as a template to predict the distribution of deep-water sand is tenuous.

Acknowledgments: The authors acknowledge the value of the many discussions with our colleagues, especially Li Xiangbo, Wei PIngsheng, Cheng bintao. The ideas presented here have also grown from numerous discussions and debates with geoscientists from many oil companies.

Quantitative bed thickness and grain-size analysis for improved understanding of deep-marine depositional systems

Pantopoulos, G.[1], Kneller, B.C.[2], De Ros, L.F.[1], Hansen, L.[2]

[1] Universidade Federal do Rio Grande do Sul, Instituto de Geociências, Av. Bento Gonçalves, 9500, CEP 91501-970 Porto Alegre, Brazil - george_pantop@yahoo.gr
[2] School of Geosciences, University of Aberdeen, Aberdeen, AB24 3UE, UK

Identification of depositional elements of deep-marine systems currently relies on detailed sedimentological studies, often requiring extensive outcrops. Components such as thinly-bedded terrace and levee sub-environments are particularly difficult to distinguish with limited datasets. The present study aims to improve the interpretation and understanding of variations among the architectural elements of submarine systems, by developing a quantitative classification scheme based on bed thickness and grain-size trends.

Data is being collected from three extensively-studied, outcropping deep-marine systems, with well-understood stratigraphic architecture: the San Fernando slope channel and levee system, in Baja California, Mexico, the Marnoso-Arenacea system, in Italy, and the Grés de Annot system, in France. Fieldwork involves mapping the external geometry of turbidite packages, gathering of bed thickness data, and in-situ grain-size measurements using visual comparator and hand-lens. Laboratory analysis consists of detailed grain-size analysis conducted in representative thin sections of sandstone samples collected during fieldwork (or by laser particle size analysis if disaggregation of samples is possible), statistical processing of collected datasets, focusing on fitting of frequency distributions, quantitative recognition of non-random facies clustering, and detailed analysis for the presence of asymmetric cycles in vertical grain-size trends.

The goal of the distribution fitting approach is to fit the observed empirical bed thickness populations to theoretical models which may reflect the depositional mechanisms. Fitting of theoretical models is being performed through numerical techniques, including maximum likelihood estimation (MLE), the Kolmogorov-Smirnov test, and the creation of a large synthetic bed thickness database, in order to produce reliable significance levels (p-values). Deconvolution of possible mixed distributions is being achieved by using MLE techniques (expectation-maximization algorithm) and Bayesian methods.

Preliminary results indicate the possible presence of mixed distribution models (mainly of lognormal type), which may be related to flow characteristics and grain size range. Facies clustering analysis based on Hurst statistics and Monte Carlo simulation is also being implemented, revealing a possible irregular, non-periodic long-term clustering pattern of low and high bed thickness values. Additional investigation is needed to confirm the use of clustering, in combination with facies characteristics, as a reliable tool for environmental interpretations of deep-marine successions. Further study will focus on the detection of non-random grain-size trends, especially in channelized depositional settings, and will also investigate their potential genetic association with particular depositional processes in proximal or distal deep-marine deposits.

This study will contribute to the predictive modeling of subsurface submarine systems. The use of bed thickness and grain size trends for the classification of deep-marine architectural elements can provide a powerful tool to assist the subsurface characterization of turbidite systems, which is crucial to improve planning of hydrocarbon exploration and oilfield development.

Shallow water strait dominated dunefield (Sardinia, Italy)

Pascucci, V.[1], Andreucci, S.[2], Cappucci, S.[3], Cucco, A.[4]

[1] Dipartimento di Architettura, Design e Urbanistica, Università di Sassari, Italy – pascucci@uniss.it
[2] Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Italy
[3] ENEA, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Italy
[4] IAMC-CNR - Istituto per l'Ambiente Marino Costiero CNR, Oristano, Italy

This study is focussed on the analysis of the submerged dunefield forming in the offshore of the La Pelosa beach (NW Sardinia, Italy), developing under shallow water strait conditions in a microtidal regime affected by NW and E-NE dominant winds. The beach, located in the NW part of the Asinara Gulf, is protected by the Asinara Archipelago from the open Sardinia Sea to the west and is connected with the gulf through a narrow, NW-SE oriented shallow strait. The depositional model proposed for strait systems comprises 4 zones: the strait-centre (zone A) is the site of maximum current speed and is characterized by no sedimentation (bedrock exposure); Zone B is dominated by dunefield systems migrating downcurrents; the strait ends (Zone C) where the current energy declines and ripples developed. Laterally, along the strait margins shoreface may form (zone D).
This model can easily be applied to the study area where the strait centre is bordered on the N-side by a small Island and on the S-side by the La Pelosa beach (Zones D). The beach is characterized by a narrow fan shaped emerged part and by a wide shoreface; both made of fine/medium sand with up to 45% quartz grains. A 450m wide and 1km long subaqueous dunefield develops on the N-side of the strait (Zone B), at the depth of -2m to -10m. Dunes are up to 7m high with a wavelength of about 140m and made of bioclastic (max 10% of quartz grains) coarse sand. They migrate toward the east. Dunes reduce in size in the easternmost part passing to ripples (Zone C) where they migrate over the upper limit of the seagrass meadow.
Models of waters circulation indicate that the strait N-side is invariable, dominated by unidirectional, E-directed current due to NW and NE coming winds. In particular, the small island is responsible for the diffraction of E-NE winds which generate a resultant E-directed current flowing through the strait. The S-side of the strait, where the La Pelosa beach develops, is affected by SE and NW directed currents depending on the prevailing winds. As a consequence the beach has suffered several periods of erosion and growth over the last 30 years.
The analysis of winds coming from the most proximal gauge to the La Pelosa beach indicates that both NW and NE-E winds experience a multiannual cyclicity with a time activity of 5 years for maximum and 3 yrs for the minimum frequency.
Multi-annual photo images together with SSS and Multibeam surveys allowed creating the below depositional model.
During low wind activity (phase 1), bioclasts from the sea grass meadow are carried westward by NW-directed currents and stored along the strait centre. In this phase La Pelosa beach growths and dunes are inactive. During high wind activity (phase 2) a dominant E-directed current re-transports sediments, stored in the strait centre, E-ward nourishing the dunefield. Phase 2 is dominated by an overall dunefield migrations eastward, the erosion of the La Pelosa beach and the almost complete remobilization of the sediments stored in the strait centre. The cyclic repetition of these two phases has allowed the formation of a wide sandy carpet and the retreat of the upper limit of the sea grass meadow.
Dunefield systems, fed by sea grass meadows, are generally placed in the middle to outer ramp, well below the wave base, of ancient temperate platform. However, in archipelago and/or in strait environments, extensive dunefield systems can develop above the wave base.

Impact of environmental conditions on microbialite formation: Thrombolites of Green Lake and Highborne Cay

Patterson, M.M.[1], Dupraz, C.P.[1, 2], Conti, A.A.[1], Visscher, P.T.[1]

[1] Center for Integrative Geosciences, University of Connecticut, Storrs, CT, USA - molly.patterson@uconn.edu
[2] Department of Geological Sciences, Stockholm University, Stockholm, Sweden

Thrombolites are non-laminated, clotted microbialites that can form by the lithification of microbial communities through the trapping and binding of sediment and mineral precipitation. This precipitation (microbially-induced organomineralization) is highly controlled by both intrinsic (microbial) and extrinsic (environmental) factors, including salinity and temperature. These intrinsic and extrinsic factors dictate the carbonate saturation index and ultimately the precipitation of carbonate minerals within the microbialite structure. Thrombolitic structures have been found throughout Earth's history (ca. 1.9 Ga) and are currently forming around the world in various locations including the Bahamas (open marine), northern New York (hard water), and Western Australia (hypersaline). By characterizing physical and chemical data from extant thrombolite-forming communities in Highborne Cay, Bahamas and Green Lake, New York, it may be possible to gain insight into the role of both the macroenvironment and the microorganisms in mineral precipitation, lithification, and overall formation of a thrombolitic structure.

In this study we use geochemical and physical data to characterize extant thrombolite-forming environments, analyze thrombolitic structure, and study the processes of microbe-mineral interactions that lead to the formation of a microbialite. To understand the extrinsic conditions affecting microbialite growth, data such as water chemistry, temperature, salinity, light, and sediment supply is important. Microbialite samples are analyzed using thin section and scanning electron microscopy (SEM) to provide a context for formation of the thrombolitic structure. This includes: amount and type of trapped and bound sediment, location and morphology of mineral precipitation, and variation between environments and even seasons.

This interdisciplinary approach provides unique insight into understanding the environmental factors that inhibit or induce microbialite formation. In characterizing extant thrombolite-forming communities using microscopic analyses of the thrombolitic fabric, mineral precipitation experiments, and geochemical and physical data from the environments, we hope to gain insight into the role both the macroenvironment and microorganisms play in mineral precipitation, lithification, and overall formation of the thrombolite structure. Additional research may provide a link to the fossil record, allowing us to use the knowledge of these structures and their formation to identify evidence of early life or life on other planets. If a link can be found between mineral morphology of thrombolites and varying environmental conditions, it may be also possible to infer the geochemistry and climate of Earth's early environments.

This research was supported by NASA, the National Science Foundation, and the Geological Society of America.

Submarine Paleoseismology along the Sumatra-Andaman Subduction Zone

Patton, J.R.[1], Goldfinger, C.[1], Djadjadihardja, Y.[2], Udrekh, H.[2]

[1] Oregon State University CEOAS, 104 CEOAS Admin Bldg., Corvallis, OR, USA 97331 – quakejay@gmail.com
[2] Bandan Penghajian Dan Penerapan Teknologi (BPPT) BPPT 2nd Building, 19th Floor Jl.MH. Thamrin 8 Jakarta, 10340, Indonesia

The paleoseismic history of earthquakes along subduction zones is an important tool to evaluate the cyclic hazards that millions of coastal residents are exposed to globally. Historic ruptures of the subduction zone fault offshore Sumatra have spanned the entire length of the subduction zone. These Sumatra-length coeval ruptures have been documented for various sections of the fault (Sieh et al., 2008; Meltzner et al., 2010, 2012) and may rupture in unison (over months to decades). From the R/V Roger Revelle, we sampled the sea floor with 109 gravity, Kasten, piston and trigger pair, and multi-cores offshore of Sumatra. We collected multibeam bathymetry and shallow seismic reflection data to locate our coring sites in places likely to be depocenters for these turbidite systems. We extend the paleoseismic record into the early Holocene with our sediment cores and into the latest Pleistocene using our seismic reflection data.

There are many potential triggers for submarine landslides and one of the principal strategies to rule out many of them is based on stratigraphic correlation of these turbidites. Most all alternative trigger mechanisms act upon either site-specific spatial extent (e.g. methane hydrate destabilization or hyperpycnal flow from high fluvial discharge) or other regionally limited processes. Alternative triggers that do act upon regions as equally extensive as earthquakes are rarer than the deposits found in our cores (e.g. bolide impacts). If deposits can be correlated from sites that have unique sediment sources and the core sites extend a large lateral distance, it is reasonable to interpret them as seismoturbidites.

We use litho- and chrono-stratigraphic methods to correlate turbidites between cores in sedimentologically isolated accretionary prism slope basins and trench settings. In 12 cores we interpret the uppermost turbidite to have been deposited as a result of seismic shaking related to the 2004 Sumatra-Andaman subduction zone earthquake. We interpret the seismic reflection data and conclude that some multi-pulse coarse Bouma Tb-Tc beds in the 2004 seismoturbidite are resolvable and that there is evidence that there may be cycles of large turbidites similar in size to the 2004 seismoturbidite. Measures of relative age (lack of oxidation in the core tops) and radiometric age (^{210}Pb and ^{14}C) support our interpretation of the uppermost turbidite. P_Sequence (OxCal software) age modelling results in an age of -60 ± 10 cal yrs BP. Using our correlations for the stratigraphic history spanning the last 6.5 ka, we estimate recurrence of earthquakes in the region of the 2004 earthquake to be 260 ± 160 years. Down-core variations of interseismic intervals show similar trends between cores, supporting our correlations. Recurrence of trans-oceanic paleotsunami records in the northern Indian Ocean is between 280 and 320 years, consistent with our estimate. Records of earthquakes in the submarine environment, found in sediment cores and seismic reflection data, are a useful tool to evaluate the cycling of strain along subduction zones.

In order to test the hypothesis that slopes along the Sumatra margin are susceptible to seismic loading, we conduct slope stability Factor of Safety (FOS) analyses for seafloor surfaces imaged with multibeam bathymetry. We first model static slope stability and then apply a seismic load for a pseudostatic stability analysis.

We thank the National Science Foundation for funding this research.

Phosphorus impact on carbonate precipitation by increase of extrapolysacharides production of marine and freshwater cyanobacteria (*Synechococcus)*

Paulo, C.[1], Dittrich, M.[1]

[1] Department of Physical & Environmental Sciences, University of Toronto Scarborough, 1265 Military Trail, Toronto, ON M1C 1A4, Canada - mdittrich@utsc.utoronto.ca

Phosphorus (P) availability can largely influence the synthesis and molecular composition of cyanobacterial extracellular polymeric substances (EPS). In aquatic systems, EPS macromolecules are widely recognized as promoters of carbonate formation. These macromolecules are extremely variable and alterations introduced by P concentration on cyanobacterial EPS is supposed to impact the calcification mechanism. In most cases, carbonate precipitation experiments with cyanobacteria are performed in solutions containing high P concentration. Consequently, the impact of P concentration on cells surface properties is neglected in the mechanism analysis.

In our study we investigated how the molecular composition and reactivity of cyanobacteria cell envelope of freshwater and marine *Synechococcus* strains vary with exposure to wide range of P concentrations (57, 115 and 230 μM). *Synechococcus* batch cultures were grown in Falcon Erlenmeyer culture Flasks (five replicates), at room temperature, constant light and their growth have been monitored during approximately 40 days. A combination of *in situ* spectroscopy techniques (Fourier Transform Infrared Spectroscopy (FTIR) and Tip Enhanced Raman Spectroscopy (TERS)), and Transmission Electron Microscopy (TEM) were used to characterize chemical and morphological the modifications induced by P concentrations in *Synechococcus* cell surface. Finally, calcium carbonate precipitation experiments were carried out using cells. Atomic Force Microscopy (AFM) was used to observe the carbonate formation on cyanobacterial cell envelope.

Our findings show that the changes in P concentration caused to the modifications of the molecular composition of the cells, as well as the morphology of the external envelopes of *Synechococcus* cells Spectroscopy analysis revealed that the content of polysacharides - a major component of cyanobacterial EPS – increases linearly with P concentration. An inverse trend was observed for the average thickness of the cell envelope, measured in TEM sections (n=25), where higher P and polysacharides concentrations relate with a general reduction of the cell envelope thickness. Carbonate precipitation were found to be strongly impacted by the presence of cyanobacteria cells. This study provides a direct evidence of the impact of P in *Synechococcus* cell surface properties and reveals the importance of environmental factors in cyanobacteria EPS production.

Late Miocene benthic foraminiferal assemblages associated with cold seeps in the active margin of the Guadalquivir Basin (S Spain)

Pérez-Asensio, J.N.[1], Aguirre, J.[2], Braga, J.C.[2], Martín, J.M.[2], Puga-Bernabéu, Á.[2], Sánchez-Almazo, I.M.[2]

[1] Department of Earth Sciences, Section of Earth and Environmental Sciences, University of Geneva, Rue des Maraîchers 13, 1205 Geneva, Switzerland - Noel.PerezAsensio@unige.ch
[2] Departamento de Estratigrafía y Paleontología, Universidad de Granada, Fuentenueva s/n, 18002 Granada, Spain

Kilometer-scale (42 km long, 1.5–8 km wide) late Miocene heterozoan carbonates crop out in an isolated NE-SW-trending belt along the so-called El Alcor topographic high, from Carmona to Dos Hermanas (Sevilla, S Spain). These carbonates consist of bioclastic rudstones and grainstones, mainly composed of fragments of small chemosymbiont 'bathymodiolins' (a group of the family Mytilidae), deposited in the southern active margin of the Guadalquivir Basin, the foreland basin of the Betic Cordillera. The carbonates are up to 20 m thick, pass laterally into terrigenous sediments, and overlie marls, silts and sandstones. Fluid escape structures (pillars and dishes) are pervasive in the carbonates. Benthic foraminiferal assemblages were studied in the fine-grained sediments laterally equivalent to, and intercalated with, the carbonates. Carbon and oxygen stable isotope analyses were performed on bulk samples and on shells from several groups of organisms, including small benthic foraminifera, the serpulid *Ditrupa*, pectinids, and small mussels. In the benthic foraminiferal assemblages, *Asterigerinata planorbis* and *Cibicides refulgens* are the most abundant species, representing more than 40% of the total assemblage, followed by *Cibicides lobatulus*, *Hanzawaia boueana* and *Reussella spinulosa*. Some of the C isotope ratios measured in shells of the different organisms show very negative values (up to -16.1‰), whereas the $\delta^{18}O$ results indicate normal marine values. Values of $\delta^{13}C$ from the benthic foraminifera show wide variation, from +0.32 to -3.5‰.

The origin of the El Alcor carbonates is very likely linked to methane seepage in an otherwise siliciclastic shelf. This interpretation is consistent with the almost monospecific composition of the chemosymbiont mussels, the depleted $\delta^{13}C$ values, and the pervasive presence of fluid escape structures. The benthic foraminiferal assemblages indicate deposition in an outer-shelf setting. The carbon isotope values of benthic foraminifera in cold seeps display a wide range of variation, from normal marine to highly negative $\delta^{13}C$. In the example studied here, the most negative values that we obtained are within the same range as the most negative values found in recent cold-seep benthic foraminifera from different areas, such as the Gulf of Mexico and the NE Pacific.

Interpretation of a Jurassic oolitic platform in the Betic Cordillera (Spain) on the basis of petrologic features of the Bahamian sediments: an application of microfacies study

Pérez-López, A.[1, 2], López-Cabrera, F.J.[1], Sawas, G.[1]

[1] Dpto. Estratigrafía y Paleontología, Universidad de Granada, 18071-Granada, Spain – aperezl@ugr.es
[2] Instituto Andaluz de Ciencias de la Tierra (CSIC-Univ. Granada), 18100-Granada, Spain

In this paper new research on the oolitic limestone unit of the Betic Cordillera is presented. This work also provides a useful methodology for the study of fractured and karstified Jurassic carbonates. The comparison of the oolitic limestone microfacies and petrologic features of the Joulters Cays sediments (Bahamas) allows an interpretation regarding sedimentary environments and evolution of a Middle Jurassic carbonate platform in the Betic domain. These Middle Jurassic white limestones are massive or crudely bedded. For this reason, various sections are measured and sampled along dip direction of beds. When it was possible to follow a bed laterally, samples were taken at intervals of 20 meters along this bed.

More than 150 thin sections were studied under microscope. Each sample was characterised by its components. Size and degree of micritization of ooids for each thin section are given. These data are compared with the published petrologic descriptions of the Bahamas platform deposits, especially of the Joulters Cays oolitic sands.

The microfacies studied are similar to the Bahamas deposits. It is possible to identify facies of different depositional environments such as tidal flats, channel/sand shoals, stabilised sand flats, ebb-tidal deltas, lagoons and “coralgal” facies. In some beds, ooids of over 1mm were found, and correspond to very high-energy deposits generated in a tidal wide channel. Marine currents are evident due to the fact that limestones with cross-stratification are observed in the field. At the same time, ooids with a big nucleus and a thin cortex are present and may indicate low turbulence in some environments. The presence of grapestones, peloids and micrite has been related to stabilised sand flats.

All of these data meet the characteristics of a Bahamian platform model. Its final evolution takes place during a transgressive stage which is the beginning of what will be the Oxfordian transgression. These white limestones are overlain by nodular carbonates that appear to represent a deepening of the shallow platform.

Reconstructing the facies distribution on an entire ancient platform is very difficult due to the complex of the sedimentary environments, which integrate the carbonate platform systems, and due to the weathering of the limestones that makes their study in the field difficult. In these cases microfacies analysis of many samples may help to identify the different sedimentary environments of a Middle Jurassic platform which shows tidal flats, channel/sand shoals, stabilized sand flats, ebb-tidal deltas, lagoon deposits and “coralgal facies”. This corroborates that extensive complex carbonate platforms like the Bahama model were developed during the Middle Jurassic, because similar carbonates are in a lot of outcrops in South Spain. This oolitic platform disappears which gives way to a deep isolated platform with deposition low rate due to the Oxfordian transgression.

Acknowledgements: This study was supported by Research Projects CGL 2011-24408, CGL2012-33281 (Secretaría de Estado de I+D+I, Spain), and by a fund from the Junta de Andalucía RNM 208.

Carnian reef biota in the Western Panthalassa domain: new data from the Sambosan Accretionary Complex, Southwest Japan

Peybernes, C.[1], Martini, R.[1], Chablais, J.[2]

[1] Department of Earth Sciences, Section of Earth and Environmental Sciences, University of Geneva, Geneva, Switzerland - Camille.Peybernes@unige.ch
[2] Geneva Petroleum Consultants International, Geneva CH-1211, Switzerland

Microfauna from the Tethyan Upper Triassic carbonate platform have been studied extensively and described in detail. However, the microfauna inventory of the shallow water carbonate from the Panthalassa domain is has received little attention.

In order to contribute to this effort, we present a new Carnian reefal microfaunal association from the Sambosan Accretionary Complex (SAC), Southwest Japan. The limestone that outcrops in the SAC represents the remains of an Upper Triassic atoll-type carbonate deposit at the top of a seamount(s) in the Western Panthalassa Ocean.

The microfauna found in the Sambosan limestone include sponges, foraminifers, algae, calcimicrobes and microproblematica, amongst others. Conodont occurrences together with foraminifers and microproblematica associations indicate that parts of the outcropping limestone in Shikoku is Carnian. This study strengthens the understanding of the taxonomic and palaeoecological changes between this reef biota, attributed for the first time uncontestably to the Carnian in Shikoku, and the previously described Norian biota.

Furthermore, our results show the crucial contribution of calcimicrobes and microproblematica as reef framebuilders and sediment producers in mid-oceanic shallow water environments during the Late Triassic.

Finally, these new data are of great interest for microfaunal diversity and palaeobiogeography studies using global databases such as Paleoreef Database or Paleobiology Database.

Acknowledgements: This project has been funded by the Swiss National Science Foundation No. RM 200020-13766.

Upper Triassic build-ups in the Panthalassa domain: insights from the Sambosan Accretionary Complex, Southwest Japan

Peybernes, C.[1], Martini, R.[1], Chablais, J.[2]

[1] Department of Earth Sciences, Section of Earth and Environmental Sciences, University of Geneva, Geneva, Switzerland - Camille.Peybernes@unige.ch
[2] Geneva Petroleum Consultants International, Geneva CH-1211, Switzerland

The Late Triassic was a time of important reef development and carbonate platform expansion. Most of the previous palaeontological and sedimentological studies on Upper Triassic shallow water environments have focused on Tethyan settings. However, since most of the pre-Jurassic oceanic crust ocean has been subducted, the shallow water environments of the Panthalassa are only recorded in the remains of former oceanic islands, preserved in circum-Pacific accretionary complexes.

In the Sambosan Accretionary Complex (SAC), Southwest Japan, Upper Triassic limestone units outcrop with other lithologies such as OIB basalt, pelagic chert and trench-fill siliceous mudstone. The limestones are terrigenous-free atoll-type limestones, which record the mid oceanic shallow water environments of the West Panthalassa domain. A sedimentological and palaeontological study of the Sambosan limestone is presented in this contribution.

Several microfacies corresponding to lagoonal, reefal and basinal settings are observed in the Sambosan limestone. The block-in-matrix mode of occurrence indicates a lack of lateral continuity between the different facies units. Nevertheless, comprehensive limestone sampling along the SAC, biotic association analysis and comparison with coeval well-defined facies zonation allow us to propose a theoretical model to illustrate the growing of the Upper Triassic build-ups of the SAC.

In order to better constrain this model, we performed an integrated biostratigraphy including foraminifera, microproblematica, sponges and conodonts.

Of particular interest are the reef facies, which contain a rich and diversified fauna that allow us to discriminate between Carnian and Norian limestone. Quantitative analyses such as point counting are performed in order to further investigate the evolution of the reef community with regards to the Carnian-Norian turn over.

This integrated approach contributes to, and documents more precisely, the mid-oceanic shallow water environments in an area less investigated than its Tethyan counterparts. Our study provides valuable insight into the depositional setting, global palaeobiogeography and reef evolution in the Panthalassa Ocean.

Acknowledgements: This project has been funded by the Swiss National Science Foundation No. RM 200020-13766.

Rapid Permian exhumation of the Montagne Noire dome recorded in provenance of Upper Paleozoic clastic strata in the Graissessac-Lodève Basin, France

Pfeifer, L.S.[1], Soreghan, G.S.[1], Pochat, S.[2], Van Den Driessche, J.[3]

[1] University of Oklahoma, 73019-Oklahoma, USA - lspfeifer@ou.edu
[2] University of Nantes, 44322-Nantes, France
[3] University of Rennes, 35042-Rennes, France

The Graissessac-Lodève Basin (southern France) preserves a thick and exceptionally complete record of continental sedimentation spanning Late Carboniferous through Late Permian time. This section records the localized tectonic and paleogeographic evolution of southern France, in the context of the low-latitude Variscan Belt of Western Europe. This study presents new detrital zircon and framework mineralogy data that address the provenance of Upper Carboniferous-Upper Permian siliciclastic strata exposed in the Graissessac-Lodève Basin. Detrital zircons in eight samples yielded significant populations that correspond with the ages of regional tectonic events, including: 500-445 Ma (widespread granitic magmatism and volcanism caused by rifting and back-arc extension along the northern Gondwanan margin), 378-331 Ma (high pressure-low temperature metamorphism and deformation during fore-arc compression, and Variscan arc-continent collision), and 330-285 Ma (magmatism, volcanism, and migmatization, chiefly in the southern Massif Central, related to post-orogenic extension and collapse of the Variscan belt). The ages and compositions of units that constitute the Montagne Noire metamorphic core complex (proximal to the west of the Graissessac-Lodève Basin) dictate detrital zircon age populations and sandstone framework mineralogy in Permian formations. Cambrian-Archean detrital zircon populations, and metamorphic lithic-rich sandstone framework compositions are derived from recycled detritus of the Neoproterozoic-Early Cambrian metasedimentary Schistes X, which formerly covered the Montagne Noire dome. Ordovician ages and subarkosic framework modes result from erosion of orthogneiss units (deformed granitoid intrusions in the lower Schistes X) that form an “envelope” on the flanks of the dome. In the lower-middle Permian units, the youngest zircon population 330-285 Ma, together with feldspar-rich compositions, reflect derivation from Late Carboniferous-Early Permian granite units in the axial zone of the Montagne Noire. Hence, these data record exhumation, and progressive unroofing of the Montagne Noire dome. The timing of core complex exhumation was previously assumed to have occurred in the Pliocene-Miocene. Our results include 330-285 Ma zircon populations, linked to sandstone compositions of polycrystalline quartz, feldspar, and metamorphic lithics, which persist through the Permian section of the Lodève Basin (Loiras-Salagou formations). Using estimates of maximum depositional ages, this requires uplift and unroofing of the Montagne Noire core (source terrane) by ca. 295 Ma. The most recent migmatization, magmatism, and deformation occurred at 298 ± 2 Ma, at ~17 km depth (based on peak metamorphic conditions in the gneissic core). Accordingly, these new provenance data demonstrate that cooling and exhumation of the core was rapid (4-17 mm/year, within error), and early (300-295 Ma), reflecting local paleogeographic uplift in the southern Massif Central during post-orogenic extension.

This research was supported by the National Science Foundation (grants OISE-1132792 and EAR-1053018). We thank George Gehrels and personnel at the University of Arizona LaserChron Center (supported by NSF-EAR 1032156) for help with detrital zircon analyses.

Climate signals in Middle Eocene deep-marine clastic systems, Ainsa Basin, Spanish Pyrenees

Pickering, K.T.[1], Cantalejo, B.[1], Scotchman, J.I.[1]

[1] Department of Earth Sciences, University College London (UCL), London WC1E 6BT, UK – ktpickering@ucl.ac.uk

The Ainsa Basin, Spanish Pyrenees, occupies a pivotal position between the non-marine, marginal marine and shallow-marine environments that acted as the sediment-supply and staging areas for sediment transfer processes into the deep-marine environments of the Ainsa Basin, and the more distal Jaca and Pamplona basins. Studies of source-to-sink systems make the Eocene stratigraphy of the Pyrenees and adjoining areas one of the best natural laboratories worldwide for understanding a complete sedimentary system. Using a wide range of proxy physical and geochemical data, we show that Milankovitch forcing at a range of astronomical scales controlled deposition of the ambient fine-grained sediments in several parts of the basin that represent approximately 70% of the stratigraphy. The driver on sandy channelised submarine-fan deposition (the principal sandbodies) remains unresolved and may be predominantly due to climatic, tectonic and/or autocyclic processes, or a combination of these.

Provenance of Miocene submarine fans in the Shikoku Basin: Results from NanTroSEIZE and implications for stratigraphic correlation of subduction inputs

Pickering, K.T.[1], Underwood, M.B.[2], Moore, G.F.[3]

[1] Department of Earth Sciences, University College London (UCL), London WC1E 6BT, UK – ktpickering@ucl.ac.uk
[2] Department of Geological Science, University of Missouri, Columbia, MO 65211, USA
[3] Department of Geology & Geophysics, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA

Seismo-stratigraphy, coring and LWD during IODP Expeditions 319, 322, and 333 (Sites C0011 / C0012) show three Miocene submarine fans in the NE Shikoku Basin, with broadly coeval deposits at ODP Site 1177 and DSDP Site 297, NW Shikoku Basin. Pickering *et al*. (2013) have shown that the sediment dispersal patterns for these fans have major implications for paleogeographies at that time. The oldest, Middle Miocene Kyushu Fan is the finest grained, has a sheet-like geometry, and was fed by quartz-rich sediment gravity-flows derived mostly from an ancestral landmass in the East China Sea. This likely sediment provenance is further supported by U-Pb zircon and fission track analysis of both zircons and apatites from sediments taken from the forearc and trench of the Nankai Trough, together with rivers from southwest Japan, that point to the influence of the Yangtze River in supplying into the Shikoku Basin prior to rifting of the Okinawa Trough at 10 to 6 Ma (Clift *et al*. 2013). During prolonged hemipelagic mud deposition at C0011-C0012 (12.2 to 9.1 Ma), sand supply continued at Sites 1177 and 297. Sand delivery into much of the Shikoku Basin, however, probably halted during a phase of sinistral strike-slip and oblique plate motion, after which the Daiichi Zenisu Fan (9.1 to 8.0 Ma) was fed by submarine channels. The youngest fan (Daini Zenisu; 8.0 to 7.6 Ma) has sheet-like geometry with thick-bedded, coarse-grained pumiceous sandstones. The pumice fragments were fed from a mixed provenance that included the collision zone of the Izu-Bonin and Honshu arcs. The shift from channelised to sheet-like flows was probably favoured by renewal of relatively rapid northward subduction, which accentuated the trench as a bathymetric depression. Understanding the stratigraphic position and 3-D geometry of the sandbodies has important implications for stratigraphic correlation throughout the northern Shikoku Basin, together with subduction-related processes, including the potential for focused fluid flow and fluid overpressures above and below the plate-boundary fault.

References

Pickering, K.T., Underwood, M.B., Saito, S., Naruse, H., Kutterolf, S., Scudder, R., Park, J.-O., Moore, G.F. & Slagle, A. 2013. *Geochemistry, Geophysics, Geosystems*, 14, doi:10.1002/ggge.20107

Clift, P.D., Carter, A., Nicholson, U. & Masago, H. 2013. *Tectonics*, doi: 10.1002/tect.20033

Contributing knowledge for conservation of the sensitive inner continental shelf of northeast Brazil

Pierri, G.C.S.[1, 2], Vital, H.[1], Esteves, L.S.[2], Leite T.S.[3], Grimaldi, G.G.[3]

[1] Postgraduate Programme in Geodynamic and Geophysics, Federal University of Rio Grande do Norte, Campus Universitário, POBOX. 1596; 59072-970, Natal – RN, Brazil - guilherme.pierri@bournemouth.ac.uk
[2] Faculty of Science and Technology, Bournemouth University, Poole, BH12 5BB, UK
[3] Postgraduate Programme in Ecology, Federal University of Rio Grande do Norte, Brazil

Economic development is increasing the pressure for use and exploration of marine space and resources in Brazil. Fisheries, oil extraction and renewable energy compete with the need for conservation of unique marine habitats. The lack of knowledge prevents informed decision-making about habitats and species at threat and the locations better suited for their conservation. The narrow (about 20 miles wide) and shallow continental shelf of northeast Brazil consists of a sensitive environment susceptible to the impacts of maritime activities, pollution, overfishing and mineral extraction. This study aims to advance the understanding of how submerged geomorphologic features (geodiversity) contribute to the biodiversity of shallow tropical marine environments. Geological, geophysical and biological surveys were conducted to identify and map the seabed and the associated biodiversity of a selected area in the continental shelf of Rio Grande do Norte (Brazil). The techniques employed in this study comprise: multi-beam and side scan sonar surveys for seabed characterization; sediment samples and biological characterization through underwater photographic and video records obtained through scuba diving. Results revealed predominance of carbonate sediments on the middle and outer shelf (mainly rhodolith beds and bioclastic sands), planar and rippled surfaces, and presence of reefs (1.5 to 2.5 m high) at different depths of 3m, 13m, 23-26m and 32m showing orientation similar to the present coastline. Similar reefs occurring in adjacent areas within the Rio Grande do Norte Shelf were described as beachrock features reflecting drowned palaeo-shorelines. In a shallow tropical shelf, these hard substrate and the rhodolith beds allow colonization and development of a diverse ecosystem, contrasting with the much lower diversity found in adjacent seabed formed by unconsolidated sediment. The intertidal reefs provide nursery grounds for a wide range of fish, crustaceans, mollusks and cnidarian species, including (*Siderastrea stellata*). The submerged reefs are mainly covered by a high diversity of algae and sponges and represent important areas for commercial species of fish, crustaceans and mollusks. Overall, the area is home for endangered and threatened marine species, including: manatees (*Trichechus manatus*), dusky grouper (*Epinephelus* marginatus), hawksbill turtles (*Eretmochelys imbricate*), nurse shark (*Ginglymostoma cirratum*) and the goliath conch (*Lobatus goliath)*. Identifying and mapping the resources at threat is a basic but essential step to support a sustainable management of natural resources, including the development and implementation of marine spatial planning, marine conservation areas and the regulation of human activities and impacts.

Acknowledgements: Thanks are due to PRH22-ANP/MCTI (CTPETRO), PETROBRAS AMBIENTAL, CAPES and CNPq for funding support.

Deepwater sandstone fairways and their interaction with substrate: analogues from the Numidian turbidites (Miocene) of Sicily.

Pinter, P.[1], Butler, R.[1], Hartley, AJ.[1], Maniscalco, R.[2]

[1] University of Aberdeen, Aberdeen, United Kingdom - ppinter@abdn.ac.uk
[2] University of Catania, Catania, Sicily, Italy;

Deepwater quartz-rich sandstones derived from mature cratons form reservoirs in many hydrocarbon provinces. These include not only rifted margins of the Atlantic but also tectonically active margins where turbidity currents have interacted with deformed substrate. An understanding of the controls on the distribution of sandstone body thickness and architecture will aid exploration and production strategies in these areas. The Numidian "flysch" is an Oligo-Miocene succession of clean, quartz-rich deep marine sandy turbidite deposits. It was sourced from the North African craton and transported northwards across the continental margin into the foredeep system of the Apennine orogen. The regional extent of these sands is well-established; they extend for some 500 km along strike and down dip with outcrops preserved within the Maghrebian-Apennine thrust belt of Sicily and southern Italy. These deposits are commonly regarded to have been deposited on undeformed substrate within ancentral foredeep, however there are evidences that the turbidity flows interact with active basin evidenced by large scale onlap and relationship between basin floor and slope substrata. This work focuses on detailed mapping of the Numidian stratigraphy and establishing the chronostratigraphic and structural relationships to underlying and overlying stratigraphic units in order to constrain local and regional basin architecture. Three areas have been studied in detail – Mt. Salici, Pollina and Muglia, Sicily – where key stratigraphic sections were logged and palaeocurrent data collected to establish facies schemes. Observations at outcrop and petrographic analysis are used to describe the facies. Modal analysis demonstrates that the Numidian sandstones are quartz-arenite type derived from craton interior. Also eleven sandstone samples were analyzed by LA-ICPMS and show detrital zircon ages strongly consistent with African source signature. Four facies associations have been identified in these two areas: massive sandstones; conglomerates; interbedded mudstone–sandstone association; and mudstone facies association. Slide-slump units are present in more mud-rich associations. The likely depositional setting is a muddy slope–apron system, cut locally by sand-rich channels, which fed channel lobe deposits. Biostratigraphic samples (foraminifera and microfossils) were collected mainly from top and base of sandstones to establish chronostratigraphic context and correlation between the sections. Panoramic views were traced to follow lateral continuity and geometry of the beds. Future work will focus on extending the study across northern and Central Sicily to better constrain the influence of basin tectonics on ponding and deflection of the Numidian gravity flows.

Combining outcrop gamma-ray logging and sequence analysis in the study of Ordovician placer deposits: Sardinia (S Italy) and Armorican Massif (NW France)

Pistis, M.[1], Dabard, M.-P.[2], Loi, A.[1]

[1] Dipartimento di Scienze Chimiche e Geologiche, University of Cagliari, 09127, Via Trentino 51, CA, Italy – marpistis@unica.it
[2] Géosciences CNRS UMR 6118 - Campus de Beaulieu, 35042 Rennes Cedex, France

This work is aimed at acquiring knowledge and understanding of some placer deposits of the Ordovician of SE Sardinia (S Italy) and W Armorican Massif (NW France). These shallow water heavy mineral concentrations were deposited in a siliciclastic storm-dominated shelf environment where the stratigraphic evolution shows an apparently random distribution of such deposits in identical facies. Heavy minerals are mainly represented by titaniferous minerals (rutile and anatase), zircon and monazite; the tourmaline is less common.

The study is based on high resolution sequence stratigraphy analysis in outcrops and backstripping procedure, supported by a petrophysical characterization and petrographic study. Gamma-ray logging has been performed on the basis of the presence of zircon and monazite minerals which are natural radioactive.

Several gamma-ray facies have been identified. A high radioactivity facies is represented by sandy beds enriched in heavy minerals, in which modal analyses show that their concentration can reach 50%. The high radioactive signal is linked to the abundance of Uranium and Thorium in zircon and monazite. Two facies with medium radioactivity have been recognized; their radioactivity is linked to the Potassium in the silty-clayey intercalations.

Stratigraphic key surfaces previously identified by the sequence analysis, are well highlighted also by the gamma-ray signal. Total Counts and K mark fourth-order sequences and stratigraphic key surfaces of third-order sequences (Maximum Regressive Surface and Maximum Flooding Surface), whereas the U and Th signal point out placer beds. The comparison between gamma-ray facies located within the depositional sequences and the results of the backstripping analysis point out that heavy mineral concentrations occur during major-order base-level rises in high-energy depositional environments (shoreface and upper offshore).

In the shallow environments of shoreface and proximal inner shelf, the storm wave action favours high-density minerals deposition, but this process seems to be controlled by allocyclic factors such as base-level variations. We proposed a model based on the sediment volume partitioning and on the superposition of cycles of distinct frequencies. During major-order cycles sea-level rises, the decreasing of terrigenous inputs in the marine environments and the amalgamation of very high frequency sequences lead concentrations of the heavy minerals. On the contrary, during sea-level falls, the high-density minerals are diluted by abundant terrigenous flux.

Acknowledgements: This work was financed by the Sardinia Regional Government (LR7-2007, N.7: “Promozione della ricerca scientifica e dell’innovazione tecnologica in Sardegna”).

Historic deep sea tsunamites in the Ionian Sea

Polonia, A.[1], Cacchione, D.[2], Gasperini, L.[1], Nelson, C.H.[3], Romano, S.[1] Vaiani, S.[4]

[1] ISMAR-CNR Bologna, Italy - alina.polonia@ismar.cnr.it
[2] CME (Coastal & Marine Environments)
[3] CSIS, University of Granada, Spain
[4] Dip. di Sc. Biol., Geol. e Amb., Univ. of Bologna, Bologna

The Calabrian Arc (CA) subduction system, part of the Africa-Eurasia plate boundary, is one of the most seismically active regions in the Mediterranean Sea, and has been struck repeatedly by destructive historic earthquakes. We investigated the effects of historic tsunamigenic earthquakes on abyssal marine sedimentation through the analysis of the turbidite record.

Resedimented units in the deep Ionian Sea represent more than 90% of the total thickness of the sedimentary record, while pelagic sedimentation is represented by thin layers bracketing turbidite beds. We dated the most recent turbidite sequences from two different cores using different radiometric methods; chronologies were refined through age modelling that provided age ranges (2δ) of each turbidite bed. The results suggest that turbidite emplacement was triggered by three historic earthquakes recorded in the region (i.e. the 1908, 1693 and 1169 events); their magnitude, epicentral location and associated tsunamis suggest fault sources located in the northern Ionian Sea or close to the coast.

Textural, micropaleontological, geochemical and mineralogical signatures reveal that turbidite beds contain a chaotic mixture of lithic clasts, plant fragments and displaced benthic foraminifera derived from several sources and bathymetric ranges. They show cyclic ordered series of color triplets (from base to top: brown, dull brown and light brownish colored units) with Zr peaks at the base of the coarse unit and Mn, Fe, Ba peaks at the top of the turbidite.

Ionian Sea turbidites, are characterized by mm- to cm-thick organic-rich layers, mainly composed of fine to medium sand, with a sharp basal contact, presumably erosional. CT scan images and the physical properties show stacked sandy units which have different compositions suggesting coeval multiple failures that synchronous triggering from earthquakes can create. The multiple coarse pulses are interpreted to the vertical stacking of material that has travelled downslope through different canyons along the margin.

In our cores the upper light brownish units of the turbidite beds were interpreted to be the product of the tsunami waves and "seiche" effects and have been referred to as the "tsunamite foam". Further geochemical and isotopic analysis on organic carbon, integrated with a detailed study of micropaleontological depth assemblages for each turbidite bed are being refined to define the source area and composition of each stacked turbidite and tsunamite cap. This will allow a better definition of the relative contribution of seismic shaking and tsunami wave processes that result in the deposition of these Ionian Sea seismo-turbidites.

A day in the life of a microbialite: innovative metaproteomic analyses of early Earth microbial analogues in Shark Bay, Australia

Pontifex, A.L.[1], Burns, B.P.[1]

[1] School of Biotechnology and Biomolecular Sciences, University of New South Wales, Sydney, NSW 2052, Australia – a.pontifex@student.unsw.edu.au

One of the major challenges in science is to identify modern living ecosystems that present unique opportunities to address fundamental questions in a range of interlinked fields. These include sedimentology, microbial ecology, geomicrobiology, and evolutionary biology. The living microbialites of Shark Bay on the western coast of Australia represent such a system. Australia not only has some of the oldest fossilised examples of these biotic structures but also possesses some of the most extensive living examples of these aquatic ecosystems. In addition to their established evolutionary significance, these microbialites are located in a hypersaline environment and are an ideal geobiological system for studying microbial processes and interactions critical to ecosystem function such as nutrient cycling and mineral precipitation. Advances in next generation (‘omic) technologies combined with classic geomicrobiological techniques has enabled unprecedented access to complex ecosystems such as these, that will facilitate a coherent understanding of modern microbialites at multiple levels simultaneously. Work presented here is the integration of metagenomic and metaproteomic analyses for the first time in the microbialite systems of Shark Bay. We focused on changes in genomic and proteomic profiles that occur over a diel cycle, as these may be critical to the processes of microbialite formation and preservation. The metaproteomes of two different Shark Bay microbialites (designated smooth and pustular microbial mats) was examined throughout the natural diel cycle - both day-time and night-time samples were analysed to delineate any differences and/or changes in protein abundance that are likely to be critical to ecosystem function. Total proteins were extracted from samples using a NoviPure® Soil Protein Extraction Kit (MO-BIO). Extracted proteins from both mat types taken over a diel cycle were analyzed by liquid chromatography tandem mass spectrometry. The resulting data was searched against metagenome databases from exactly the same samples. Metagenomic data obtained revealed potentially novel pathways relating to carbon fixation, nitrogen and sulfur cycling, and fermentation. It suggests ancient forms of carbon fixation could be active in modern day Shark Bay stromatolite systems. Dissimilatory sulfate reduction pathways out number sulfite oxidation by at least an order of magnitude, pathways shown in other systems to promote either precipitation or dissolution. After scaffolding against the metagenomic data, the metaproteomic results revealed over 500 proteins with a broach range of functions, as well as identifying a number of proteins from known phyla. Changes in type and abundance of proteins were noted both between mat types and between day and night. Interestingly, we have identified key light-harvesting proteins involved in photosynthesis in *Synechococcus* sp**.**, which are known oxygenic phototrophs. We have also identified numerous enzymes involved in nutrient cycling such as sulfite reductase subunits from novel uncultured sulfate-reducing bacterium, as well as specific enzymes involved in glycolysis. Furthermore, proteins involved in carbon concentrating mechanisms, ATP synthesis, protein folding, and many other cellular functions have also been identified. Through the application of a rational and integrated approach, this research has provided valuable insights into these evolutionally significant biological systems. and will facilitate rational predictions on past environments and build valuable models in understanding early earth communities. It has enabled for the first time a dynamic and holistic view of these ecosystems and the complex network of processes occurring through space and time.

Revealing the recurrence rate of megathrust earthquakes along the Alaskan-Aleutian subduction zone using lacustrine records

Praet, N.[1], Moernaut, J.[2, 3], Van Daele, M.[1], Kempf, P.[1], Haeussler, P.[4], Strupler, M.[3], De Batist, M.[1]

[1] Renard Centre of Marine Geology (Ghent University), BE-9000 Ghent, Belgium - nore.praet@ugent.be
[2] Instituto de Ciencias Ambientales y Evolutivas (Universidad Austral de Chile), 14101 Valdivia, Chile
[3] Geological Institute (ETH Zurich), CH-8092 Zurich, Switzerland
[4] US Geological Survey, 99508 Anchorage, United States of America

On March 27, 1964, the "Good Friday Earthquake" ruptured an 800 km-long segment of the Alaskan-Aleutian megathrust, representing the largest measured earthquake in North America (M_w 9.2). Recurrence rates of such megathrust earthquakes are typically in the order of hundreds of years. In order to acquire statistically robust data, high-quality paleoseismological records are necessary, which are able to extend the historical evidence thousands of years back in time. Lake sediments can produce such paleoseismological records since seismic shaking can generate subaquatic landslides and turbidites, which form distinct resedimentation deposits that are interbedded within the background sediments.

During a reconnaissance survey in 2012, several short cores and high-resolution seismic data (3.5 kHz pinger source) were collected in Eklutna and Skilak Lake, Southern Alaska. These data showed that both lakes have the potential to yield a calibrated lacustrine record of megathrust earthquake recurrence.
In spring 2014, we recovered long sediment cores at 5 locations throughout Eklutna Lake with respectively 15, 16, 17, 9 and 9 m of total length. In 2015, we aim to retrieve 6 long cores from Skilak Lake.

These core data will be interpreted in the framework of the seismic stratigraphy of the lakes. A preliminary seismic-stratigraphic framework of Eklutna and Skilak Lake has been established by determining and picking seismic horizons on several seismic profiles throughout the lake basin. A seismic horizon was here defined by the presence of landslides and/or (mega)turbidites on the seismic profile.

The seismic data revealed the presence of successive seismic horizons with mass-transport deposits and megaturbidites. Mapping these horizons allowed the construction of event maps that show the spatial distribution of the mass-wasting deposits. Multiple mass-wasting deposits are present for each event in both lakes, implying triggering by strong earthquake shaking. In Eklutna Lake, 10 megathrust-earthquake events can be identified, while Skilak Lake shows 7 events. Hence, Eklutna and Skilak Lake show a different earthquake-recording capacity: Eklutna shows evidence of more frequent but less voluminous events. This can partly be explained by the larger sedimentation rate (Pb/Cs data of the short cores reveal a sedimentation rate of 0.432 cm/yr for Eklutna and 0.253 cm/yr for Skilak Lake), resulting in more rapid loading of the slopes, which can lead to a more frequent occurrence of instabilities.

Analysis of the long cores from Eklutna and Skilak Lake through these mass-wasting levels, will make dating of past megathrust earthquakes possible, for the last thousands of years.

The length (5000 years) and high-resolution chronology (i.e. varved background) of the lacustrine record, using a combination of seismic-stratigraphy and long core data from both lakes, will allow to generate a unique, high-quality dataset of megathrust earthquake recurrence rate, mode and pattern along the Prince William Sound segment of the Alaskan-Aleutian subduction zone. This will be crucial for understanding the seismic hazard of Southern Alaska and in particular the more densely populated city of Anchorage.

Geomorphology and sedimentology of a Modern isolated carbonate platform: the Glorieuses Archipelago, Sw Indian Ocean

Prat, S.[1], Jorry, S.[1], Jouet, G.[1], Camoin, G.[2], Vella, C.[2], Le Roy, P.[3], Pastol, Y.[4], Caline, B.[5]

[1] IFREMER, Ctr Brest, Unité Géosciences Marines − BP.70 F-29280 Plouzané, France – Sophie.Prat@ifremer.fr
[2] CEREGE, Europole de l'Arbois − BP.80 F-13545 Aix-en-Provence cedex 4, France
[3] Univ. Bretagne Occidentale, IUEM, LDO UMR 6538 − F-29280 Plouzané, France
[4] SHOM, Centre Hydrographique − BP.426 F-29275 Brest, France
[5] TOTAL Exploration and Production, CSTJF, Avenue Larribau − F-64000 Pau, France

To improve the interpretation of facies heterogeneities in fossil reefs, the study of modern carbonate platforms is used to identify factors controlling the distribution of carbonate sands according to specific platform configuration (i.e. barrier reefs and isolated carbonate platforms). Although the role of sea-level changes, tectonics and sedimentation on the dynamics and evolution of tropical carbonate platforms has been widely studied, factors controlling the sediment variability are poorly known.

This study presents the geomorphological and sedimentological analysis of the Glorieuses Archipelago, an isolated carbonate platform located north of Madagascar. The dataset consists of dredges, sediment cores and sparker seismic lines collected in the frame of the REEFCORES project in 2011 and in 2013, and bathymetric/topographic (Lidar) data acquired in 2011 (Litto 3D project). Particle size analysis and composition of carbonate grains are used to characterize the distribution and heterogeneity of sand accumulated on the isolated platform.

Main results show that the Glorieuses Archipelago is organized in several morphological units: an outer platform, a barrier reef, an apron, a semi-enclosed (<15 m depth) and an open (> 15 m depth up to 25 m) lagoon. The carbonate constituents are dominated by segments of *Halimeda,* larger benthic foraminifera, coral debris, molluscs, red algae, echinoderms, bryozoans and sponges. The absence of carbonate mud all along the archipelago islands can be explained by the exposure of lagoon to the open ocean. According to the shape and the position of intertidal sandwaves, the present arrangement of these well-sorted fine sand accumulations appears to be strongly influenced by the flood tidal current. The spatial heterogeneity of carbonate sediments on this isolated platform is mainly controlled by the distribution of carbonate producers and hydrodynamic factors (currents, waves, storms, etc). Seismic lines acquired from semi-enclosed to the upper slope of the platform demonstrate that most of the sediment is shedded along the leeward margin.

At least, the sedimentary model proposed for isolated carbonate platforms allows to define the carbonate production area, the shallow accumulations and transport path which contribute to the sedimentary export to the steep seamount slopes and to the deep basin.

Climate - tectonic signatures in sedimentary packages of Rukmawati River, Kachchh, Western India

Prizomwala, A.D.[1, 2], Chauhan, G.[2], Bhattacharya, F.[1], Thakkar, M.G.[2], Rastogi B. K.[1]

[1] Institute of Seismological Research, Raisan, 382009 - Gandhinagar India - rchndas7@gmail.com
[2] Department of Earth and Environmental Science, KSKV Kachchh University, 370001 - Bhuj, India

Dryland Rivers by virtue of their preservation potential, serve as suitable archives towards understanding climate-tectonic coupling. In the present study we investigated the fluvial records of southerly-draining rivers in the semi arid southern Kachchh, western India. Indian Summer Monsoon is the major source of moisture to the fluvial system which drains into the Gulf. Additionally the terrain is one of the most tectonically active regions in India. Considering these, it is therefore suggested that the temporal changes in fluvial sedimentation would help in reconstructing the influences of these forcing factors.

Present study investigated the Rukmawati River which originates from the Katrol Hill Range in the north and flows towards the south into the Gulf of Kachchh. Along its course, the river cut across the east-west trending major geologic structures and lithological formations. Post depositional incision by the Rukmawati River has exposed Lithofacies assemblages. These are documented in upper, middle and lower reaches of river. A preliminary optical age on the lowermost litho unit suggests that fluvial aggradation in the region was initiated after the Last Glacial Maximum (LGM) during the onset of the Indian Summer Monsoon.

The generalized stratigraphy of the terrain comprises of Mesozoic bedrock overlain by unit-1 which is clast supported gravel (Gcm). This is followed above by unit-2 comprising of crudely laminated gritty sand (Sp). Overlying this is unit-3 which consists of massive sand (Sm) which has also undergone scouring. Above this is the unit-4 which includes crudely laminate miliolitic sand (Ss) which is finally capped by unit-5 consisting of debris flow (Gmm, Gcm).

The Gcm facies lying above the beveled planar bedrock represents erosional contact which suggests that sedimentation occurred after the beveling of the bedrock. This unit is considered as a marker horizon deposited throughout the terrain after LGM (18 ka). The beveling of the bedrock occurs due change in the ratio of vertical to lateral erosion which is a characteristic of the down-cutting river in an active terrain. The unit-1 lying above is a hyper concentrated gravity flow unit which consists of sediment budget mobilized from the catchment areas. The crudely-laminated and massive unit-2 and 3 (Sp, Sm) lying above this unit suggests strong monsoon condition deposited during the early Holocene period (6-12 ka). The scour and fill structures present in this unit represents typical characteristic of Dryland Rivers which scours during the increasing limb of the flood hydrograph and fills during the recession of the flood. Finally the sedimentation terminates with debris flow. From chronology of the lowermost unit, it could be suggested that the sedimentation in the Rukmawati river valley commenced after the LGM (~18 ka) with the deposition of hyper concentrated gravity flow unit.

Climate-Tectonic Interactions in the Fluvial Sequences of the Eastern Northern Hill Range, Kachchh, Western India: Luminescence Chronometry and Geomorphic Evidences

Prizomwala, S.P.[1], Solanki, T.[1], Chauhan, G.[2], Bhatt, N.[3], Basavaiah, N.[4], Thakkar, M.G.[2], Rastogi, B.K.[1]

[1] Institute of Seismological Research, Raisan, 382009 - Gandhinagar, India – siddharth_prizomwala@yahoo.co.in
[2] Department of Earth and Environmental Science, KSKV Kachchh University, 370001 Bhuj, India
[3] Department of Geology, The M. S. University of Baroda, 390002 – Vadodara, India
[4] Indian Institute of Geomagnetism, New Panvel, 410218 - Navi Mumbai, India

Kachchh region of western India is one of the most seismically active intraplate regions on earth, which has experienced three catastrophic events in past two centuries (1819 Allah Bund Earthquake ~ Mw 7.8; 1956 Anjar earthquake Mw ~ 6.0; 2001 Bhuj Earthquake Mw ~ 7.7). Kachchh Mainland Fault (KMF) is a 150 km long E-W oriented south dipping reverse fault, situated in the north of Northern Hill Range of mainland Kachchh. The KMF is neotectonically and seismically active fault substantiated by distinct geomorphology and earthquake history. It is explicated as steep north facing scarp in Northern Hill Range (NHR) abutting against the Quaternaries of Banni Plain and Great Rann of Kachchh towards north. Several ephemeral rivers namely Kaila, Pur, Kaswali, Lothia, Nirwaha and Khirsara originate from the Katrol Hill Range in south and drain northwards into the Banni Plains / Great Rann of Kachchh. In order to document the climatic / tectonic signatures archived by these fluvial sequences we studied them for their lithofacies assemblages and geomorphic variability. The major lithofacies documented in these fluvial sequences are Gcm, Gmm, Sm, Sh and Ss. Overall atleast two phases of aggradation and two phases of incision were documented. The aggradational phases were characterized by Gmm and Gcm facies overlain by Sm and Sh facies. Oldest aggradational phase occurred during the Late Pleistocene and youngest phase during the Middle to Late Holocene. The incision phases were marked in the form of two levels of terraces in Quaternary sediments. The incision phase - 1 occurred during the Early Holocene, most likely triggered due to the enhanced strength of the Indian Summer Monsoon. During the Late Holocene the western India, experienced relatively weaker and fluctuating climatic conditions. The incision phase - 2 took place during the Late Holocene, most likely due to tectonic uplift along the KMF, as evidenced by palaeo-seismological investigations. Several geomorphic anomalies like strath terraces, stream capture, offset channels, defeated streams, pressure ridges and offset ridges mark the expression of tectonic activity along the KMF.

Interestingly the geomorphic anomalies provide a strong hint of segmented nature of KMF owing to several NW-SE, NNW-SSE and NE-SW oriented transverse faults. The KMF scarp is displaced by few meters to several hundred meters by these faults, indicating the tectonic activity along these transverse faults is younger than the KMF. The OSL chronology from sediment records provides robust support to this claim hinting at varying incision / uplift rate of KMF along different segments. Additional OSL dating is in progress which would shed light on the varying degree of timing of uplift / incision in fluvial sequences of eastern Northern Hill Range.

Sustained and surge-type turbidites in the Cergowa Beds submarine fan (Oligocene, Outer Carpathians, Poland and Slovakia)

Pszonka, J.[1], Wendorff, M.[2], Žecova, K.[3]

[1] The Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, ul. Wybickiego 7, 31-261 Kraków, Poland – jpszonka@min-pan.krakow.pl
[2] AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków, Poland
[3] Štátny Geologický Ústav Dionýza Štúra, Mlynská Dolina 1, 81704 Bratislava, Slovakia

The lenticularly-shaped lithosome of the Cergowa Beds (Oligocene of the Outer/Flysch Carpathians; the Dukla and Fore-Dukla Tectonic Units in Poland and Slovakia) is composed of two main lithofacies: (i) the sandstone lithofacies localized in the axial part of the lithosome, and (ii) sandstones interbedded with shales that occur in the marginal parts of the lithosome. Sedimentary features and facies of the Cergowa Beds imply a submarine fan deposited by sediment gravity flows. Sediment provenance and interpretation of flow mechanisms are based upon the most recent analysis of detailed/bed-by-bed sedimentological logs, facies associations and micropalaeontological data.

The presence of recurrent-homogeneous structures (e.g. Tbbb… or Tccc…) and recurrent-fluctuating structures (e.g. Tabcbc..., Tbcbc... or Tcbcb...) in thick- and very thick beds of some sandstone-dominated facies of the Cergowa Beds suggest sustained/long-duration turbidity currents. Abundant coalified plant detritus including large fragments of tree-trunks (up to 2 meters long) documents a strong influence of the deltaic supply system and located not far from the deposition site. We suggest that the sustained turbidity currents responsible for deposition of this facies were generated by hyperpycnal effluents. Other facies of the Cergowa Beds constitute of classical bottom-truncated Bouma sequences deposited by surge-type turbidity currents of medium and low concentration (e.g. Tbcde, Tcde, Tde). In summary: a significant part of the sandstone-dominated facies represent hyperpycnal effluent from delta front located close to shelf-margin, whereas the contrasting fine-grained turbidite facies were generated by slumps derived from the slope marginal to the Cergowa basin; this is further supported by the micropaleontological data.

On the basis of the diagnostic species, the Cergowa Beds were assigned to the zone NP 23 (Lower Kiscellian) and NP 24 (Upper Kiscellian). The endemic species present in the assemblages of nannofossils from biozone NP 23 (*Reticulofenestra* cf. *ornata* and *Transversopontos fibula*) are characteristic for brackish and shallow water. This lends further support to the interpretation of delta-fed hyperpycnal effluents as the source of thick-bedded facies of the Cergowa Beds submarine fan.

Precambrian phosphorites and the biogeochemical cycling of phosphorus on the early Earth

Pufahl, P.K.[1]

[1] Acadia University, Earth and Environmental Science, Wolfville, Nova Scotia, B4P 2R6, Canada – peir.pufahl@acadiau.ca

Precambrian phosphorites are rare and fundamentally different from those in the Phanerozoic. True phosphorite does not exist in the Archean because the weathering of phosphate-poor, mafic crust under an anoxic atmosphere limited its accumulation. The appearance of phosphorite in the early Paleoproterozoic approximately coincides with the Great Oxidation Event (ca. 2.4 to 2.3 Ga) and the beginning of oxic chemical weathering of the continents. Phosphorite vanished during the Mesoproterozoic and reappeared in the Neoproterozoic during the Neoproterozoic Oxygenation Event (ca. 700 to 550 Ma).

Sedimentologic data from the Paleoproterozoic Michigamme Formation (ca. 1.85 Ga), Lake Superior region of North America, and the Neoproterozoic Sete Lagoas Formation (ca. 610 Ma), central Brazil, suggests most Precambrian phosphorites were small and restricted to shallow, non-upwelling related paleoenvironments. Phosphatic facies are stromatolitic and composed of peritidal microbialites and tide deposited lenticular- and flaser-bedded sandstones. In the Sete Lagoas Formation the absence of coarse terrigenous clastics and abundance of silt with fine, abraded quartz grains suggests an aeolian source of phosphorus. Phosphogenesis is interpreted the consequence of Fe-redox pumping and microbial respiration of sedimentary organic matter below a suboxic seafloor that developed in photosynthtically produced, nearshore oxygen oases. In deeper, anoxic environments these redox-sensitive phosphogenic processes were suspended in the water column, precluding the concentration of phosphorus in sediment.

Such shallow-water phosphorite contrasts younger, larger late Neoproterozoic and Phanerozoic phosphatic deposits. These phosphorite giants formed in deeper upwelling environments after the Neoproterozoic Oxygenation Event ventilated the ocean. Thus, the increasing size of phosphorites through the Neoproterozoic is interpreted to record the progressive oxygenation of the water column and concomitant expansion of phosphogenic environments. This concentration of bioavailable phosphorus in an array of benthic settings may have been an important precondition for the Ediacaran evolution and diversification of multicellular animals.

Acknowledgements: Funding was provided by a Natural Sciences and Engineering Research Council of Canada Discovery Grant and numerous industry grants. Presented ideas were developed with Eric Hiatt, Maisa Abram, Claudio Porto, Renee Delisle, Justin Drummond, Cole Edwards, and Gabe Nelson.