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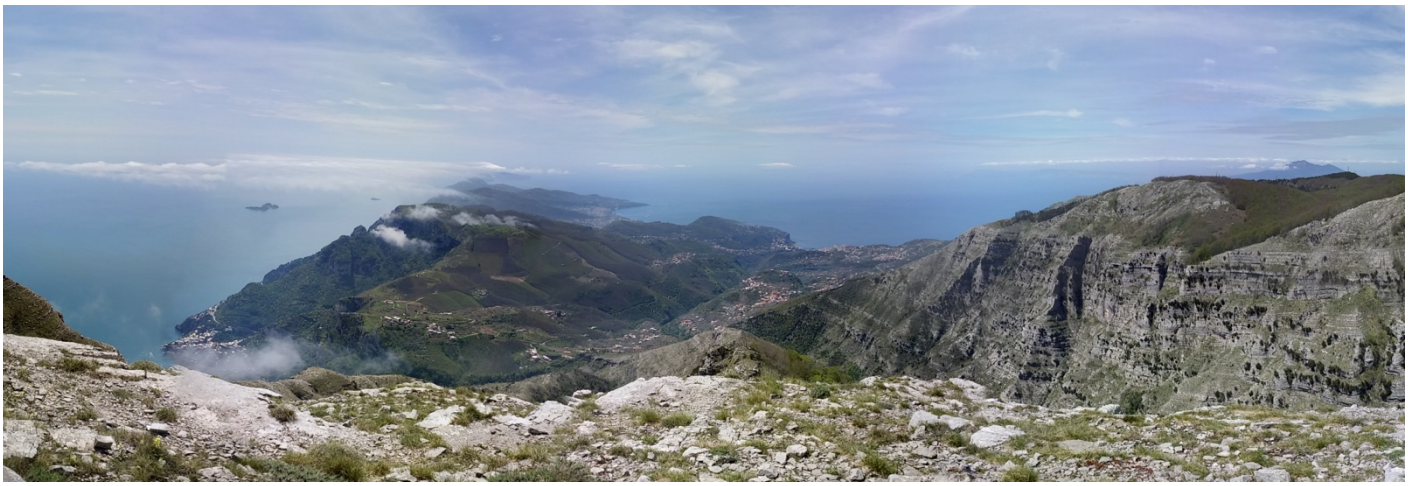

ABSTRACT BOOK


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Challenges and Success in Low Temperature Oxygen Diffusion Studies of Biocarbonates

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Measuring and observing diffusive phenomenon in mineral systems at low temperatures (<300°C) is notoriously challenging. Low temperature diffusion is considered to occur too slowly to be recognized on short experimental time-scales, leaves no textural evidence, and its effects can be easily overprinted by or misidentified with more rapid processes such as adsorption, recrystallization, or pseudomorphic dissolution/precipitation. Despite this, recent studies suggest that diffusive processes can be measured and can influence isotopic compositions in biocarbonate minerals at low temperatures and short time scales without leaving any textural evidence, which challenges the reliability of "pristine biominerals" for paleoclimate reconstructions. Here, we report our efforts, and success to measure oxygen isotope diffusion coefficients derived from foraminifera tests, belemnite rostra, and mollusc shells and to apply the calculated diffusive coefficients using numerical modelling to reconstruct the resulting effects on the paleotemperature record. To calculate oxygen diffusion coefficients in biominerals, we incubated samples in "wet conditions" i.e., ^{18}O-enriched calcite saturated (saturation index = 1) artificial seawaters, and in "dry conditions" i.e., with only $C^{18}O_2$ gas, over a wide range of temperatures. Our results demonstrate that oxygen isotope diffusion (grain boundary and lattice) occurs more rapidly in biocalcites than abiotic calcites. This is likely due to the poly- and nanocrystalline structure of most biominerals that generates shorter diffusive pathways, and an abundance of organic compounds interwoven in the biomineral ultrastructure. The nanocrystalline and organic nature of the biominerals; however, also leads to many experimental difficulties due to biomineral recrystallization at temperatures >200 °C even in fluids at calcite saturation. Through multiple experimental procedures, we can address these challenges and demonstrate the role that diffusion plays in biasing paleotemperature records.

Petrographic characteristics of the Hamma-Bouziane travertines (Eastern Algeria)

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The Constantine region boasts an abundance of Plio-Quaternary travertines. Those of Hamma Bouziane are related to the thermal springs which have dried up or still exist at the base of the Bergli massif.

This massif comprises neritic limestones of Cenomanian age and red clay-sand formations of Mio-Pliocene age. Within these travertines, four lithotypes have been identified: the arborescent lithotype (micritic arbustiform shrubs, sparite fan shrubs crust, and sparry spherules), the laminar lithotype is characterised by quartz-grained microsparite laminae and Algal mattes with a stromatolithic appearance. The lithotype related to karstic cavities is characterised by a concretion of calcite crystals around arborescent travertine. the fourth lithotype, relatively recent, is composed of reddish detrital sediments with plant debris representing micritic to microsparitic microfacies with peloids, and very finely grained quartz and sparitic plant debris. This preliminary work should be developed on all the travertines of the Constantine region in addition to chemical analyses in order to understand and specify their mode of formation.

Impact of diagenesis on Pre-salt lacustrine carbonates: Implications for reservoir quality

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South Atlantic Pre-salt successions represent one of the largest hydrocarbon provinces in the world. The Aptian carbonate reservoirs of Santos Basin Barra Velha Formation are responsible for most of Brazil oil production. These rocks formed under evaporative conditions in a broad, relatively shallow hyperalkaline lake. The *in situ* rocks are composed of a variable mix of calcite spherulites and fascicular shrubs, and Mg-clay matrix, while the reworked rocks are composed of intraclasts of these constituents. High-frequency intercalations between *in situ* and reworked deposits are extremely common in the Pre-salt, and represent significant variations in reservoir quality. Redeposited samples are on average significantly more porous than *in situ* samples due to the presence of matrix in the latter, although both lithotypes may be extremely impacted by diagenesis. Diagenetic modifications may result in large changes in the initial reservoir quality and, therefore, understanding their distribution and patterns is of utmost importance. The focus of this study is to evaluate the diagenetic patterns on different lithotypes and their impact on reservoir quality in a highly altered well of the Santos Basin. Detailed petrographic analysis revealed that the base of the well is predominantly constituted of spherulitic and fascicular calcite intraclasts and, subordinately, of reworked clay ooids replaced by calcite (with volcanic and carbonate intraclastic nuclei) and holocrystalline and hemicrystalline volcanic fragments. Interparticle porosity was obliterated by macrocrystalline to blocky calcite cement and by the moderate to high degree of compaction, evidenced by abundant intercutting and sutured interparticle contacts, highly deformed volcanic rock fragments and microstylolites. The mid-section of the well is predominantly composed of muddy spherulstones with significant matrix dissolution and replacement by blocky and saddle dolomite, criptocrystalline silica and microcrystaline quartz. Lamellar dolomite/magnesite filling matrix-contraction pores and replacing matrix is also common, often providing the only indication of the original presence of matrix. The top section is characterised by intense silicification, occluding all pre-existing porosity, and by pseudomorphic dolomitization of *in situ* lithologies, perfectly preserving the aggregates original textures. These dolomitized muddy spherulstones display large volumes of matrix dissolution porosity. These patterns represent a significant deviation of the characteristic quality distribution in the Pre-salt reservoirs. Understanding the patterns and impacts of post-depositional alterations on the Pre-salt extraordinary deposits is of key importance to decrease exploration risks, as well as to optimize their production.

Stablishment of paragenetic relations and their impacts on petrophysical behaviour of carbonatic and argillaceous carbonatic facies from pre-salt fields, Santos Basin, offshore Brazil

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We studied thin sections from xx samples of carbonatic to argillaceous-carbonatic litotypes of common occurrence at pre-salt fields from Santos Basin, offshore Brazil, in order to evaluate paragenetic relations and their impacts on reservoir quality of these kinds of rocks.
The methodology adopted in this work is based on characterization of the most important mineral phases that compose the solid matrix framework, interpretation of the relations among them, and establishment of "genetic pathways" (groups of similar rock textures, based on types, timing and intensity of the geological processes interpreted and registered on paragenetic charts). Through this information we can evaluate the porous system behavior at the main stages at each genetic pathway, resulting in significant impacts on the quality of the pre-salt reservoirs. By using different analysis (porosity, permeability, porosimetry and microCT) we can understand how the relation among different mineral phases influence the distribution of the elements of the porous system. In terms of porosity, we consider it here as a volume phase (represented, at a petrographic scale, as an area) that evolves by changing location and geometries of its elements, thus getting complexes porosity and permeability correlations.
We identified six genetic pathways, all of them with the same original point. Each pathway is composed by slightly different textures that represent "stages of evolution". They are called "submicrotextures". Each pathway represents a specific relation of timing and intensity of a sort of geological processes identified. For the samples of each pathway analysis were conducted, and through the results it could be interpreted the influence of each mineral constituent on petrophysical characteristics, often related to the presence of specific mineral phases. We interpret that the paragenetic and compositional characteristics materialize the intensity and relations among processes that each sample was submitted. Beyond the solid matrix alterations, these processes modify the characteristics of porosity, promoting modifications on shape, size and distribution of porous chambers and their connections. To understand these impacts and relate them to specific paragenetic interpretations is worth to correlate the geological processes identified (spatially and temporally distributed at the conceptual models) to their results. This seem to be a safe way to acquire predictability at facies and petrophysical properties distribution on static models. The results obtained through this work were incorporated into the geological and flow simulation models of the pre-salt reservoirs, contributing both to the adjustment of dynamic data and to the field production forecast.

The temporal variability of the Holocene $CaCO_3$ deposition at four alkaline fens in the young glacial area of central Europe

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The factors responsible for the temporal variability of $CaCO_3$ (tufa) deposition are recognised at four alkaline fens located in north-eastern Poland and Latvia, within the extent of the Weichselian glaciation: Turtul (Tu), Puszcza Romincka (PR), Maitiku (Mai), and Lustūžkalns (Lus). Methods used include plant macrofossil, mollusc, loss on ignition and $\delta^{13}C$ and $\delta^{18}O$ analyses. The chronology of the sediments is based on ^{14}C dates from plant macrofossils. The time frames of $CaCO_3$ accumulation varied between the fens. In north-eastern Poland, tufa was deposited between ca. 11650 and 50 cal yr BP on PR and between ca. 9250 and 5400 cal yr BP on Tu. The early Holocene onset of $CaCO_3$ accumulation was associated with the activation of groundwater circulation following permafrost degradation. The decline in tufa deposition ca. 5400 cal yr BP in Tu was likely related to climate cooling in the mid-Holocene. Declined temperatures affected the conditions of tufa precipitation and indirectly decreased the Ca^{2+} supply controlled by chemical denudation of the scattered $CaCO_3$ from glacial sediments in the aquifer. Also, after progressive leaching during the early Holocene, this carbonate reservoir became a less efficient Ca^{2+} source. The Holocene-long tufa deposition at PR fen, exceptional in north-eastern Poland, likely resulted from site-specific hydrogeological conditions assuring an efficient supply of Ca^{2+}-rich artesian waters. At Mai and Lus, enhanced tufa accumulation has been observed only since ca. 3500-3200 cal yr BP, when the increased climate humidity resulted in higher water levels at bogs and fens in Latvia. The Palaeozoic limestone bedrock, an inexhaustible source of Ca^{2+} ions, assures intensive $CaCO_3$ precipitation at those sites. The high temporal variability of tufa deposition at the fens investigated can be attributed to the complexity of factors controlling $CaCO_3$ precipitation with the critical influence of local climate fluctuations, type and richness of Ca^{2+} source, and hydrogeological conditions.

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U-Pb dating of dolomite veins unveil paleo-tectonic history of Apennine Carbonate Platform

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In southern Apennines, dolomites are widely distributed and commonly found at multiple stratigraphic levels within the thick Late Triassic to Late Cretaceous carbonate platform succession. These massive, replacive matrix dolomites are often associated to several generations of veins with white-sparry saddle dolomite, generally followed by calcite.

A few samples of Upper Triassic and Lower Jurassic dolomite veins from Lattari and Matese mountains (southern Apennines) have been analyzed using *in situ* U-Pb dating technique. The collected dolomite samples were studied using polished slabs with subsequent petrography, scanning electron microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS) and cathodoluminescence (CL). Petrographically, dolomite crystals are very coarse (typical saddle dolomites), euhedral and granular anhedral (having undulatory extinction), geodic, occupied irregular vugs and fractures and is usually followed by poikilotopic calcite precipitation. All dolomites in veins are non-luminescent.

The U-Pb data provided four main clusters of dates: Late Triassic/Early Jurassic age (200 Ma), Late Jurassic (160 Ma), Albian-Cenomanian (100-90 Ma) and Eocene-Oligocene (50 and 35 Ma). Each age corresponds to well established extensional phases affecting the Apennine Carbonate Platform on a regional scale: the formation of intraplatform restricted basins during the Mesozoic and the pre-orogenic extension of the platform. The U-Pb data suggest that each of these tectonic events promoted fluid flow, and related hydrothermal dolomitization. The microthermometry of primary aqueous fluid inclusions present in sparry dolomites evoke a possible entrapment temperature of 120-150°C, exceeding the maximum burial temperatures congruent with the subsidence history of the area.

The absence of a significant source of clastic, silicate sediments within the thick carbonate pile, and thus of Mn and Fe, is probably the reason of the absence of any luminescence. A local source of Mg, and hence a very low water-rock ratio is suggested by the fact that dolomite veins develop only when the host rock is matrix dolomite. This is especially clear in relatively small, stratabound bodies of dolomites occurring in the Lower Cretaceous.

Consequently, a proposed model implies the circulation of warm (hydrothermal) dolomitising fluids through Mesozoic and Paleogene extensional faults in the Apenninic platform, which lacked external sources of Mg, Mn and other metals and had low water-rock ratio (i.e., close system).

From present study, U-Pb dating technique is envisaged as a significant tool, which can unravel and attest different-age tectonic events, which are preserved but obscured in compositionally and texturally homogenous dolomites.

Distribution over geologic time of seismic-scale, early-karst features in shallow-water carbonates

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Karst-related features are among the most used diagnostic criteria to recognize carbonate deposits in seismic data. However, are seismically resolvable karst features, which are related to large-scale, early post-depositional, dissolution process by meteoric water, uniformly distributed along geologic time or have they occurred more frequently in specific ages?
For this research, approximately 700 publications, relative to shallow-water carbonate systems of different ages, spanning from Precambrian to present day, with a worldwide distribution including more than 110 sedimentary basins, have been studied. Conclusions suggest that seismically resolvable karst features, which are related to large-scale, early post-depositional, dissolution process by meteoric water, are more common in some geologic ages and sedimentary settings than others.
Specifically, these features are more likely to be observed in icehouse, non-ramp, carbonate deposits, suggesting that icehouse, high-frequency, eustatic movements, could actually contribute to large-scale, diagenetic, dissolution processes, to a greater extent than it has been speculated so far. Such conclusion can be of significant help in derisking carbonate exploration activity.

Modern Microbial Carbonates Deposits in South America: New insights of sedimentation and diagenesis in alkaline lakes.

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The sedimentation in the alkaline lakes could be understood as a product of intrinsic and extrinsic factors' interaction, where both can exert influence with alternating or progressive predominance due to the large-scale geochemical scenario, promoted by the tectonic and geomorphological settings, the climate and hydrology, the sedimentation, and the environments of deposition. Sedimentological studies of modern carbonate deposits in extreme environments provide access to a better understanding of physical-chemical reactions under the intense influence of natural conditions of desert climate, such as UV radiation, temperature variation, altitude, and heavy winds. Modern carbonate environments, where alkaline lakes are forming under comparable geomorphological, biological, climatic, volcanic, and tectonics characteristics as those during the formation of the Aptian Pre-Salt lakes on the Brazilian continental shelf, are possible analogues to improve our understanding of the physical-chemical processes involved the formation of ancient carbonate deposits. Nevertheless, it is difficult to study a single modern example, which fulfils all the criteria required to define a realistic evolutionary model for the Aptian equivalent. Thus, we have selected for our evaluation several modern alkaline lake locations, which form under variable environmental conditions, e.g., the Pantanal, Central Brazil, and Patagonia, Chile. These environments present vastly different conditions, which can furnish important insights, and taken together provide fundamental information to decipher relationships between the inorganic and organic processes involved in carbonate reservoir formation. In the Pantanal region, thousands of lakes are distributed throughout one of the largest fan river systems. Microbial activity in many of these water bodies mediates the production of carbonates associated with authigenic clay mineral precipitation, e.g., smectite. In Chile's Patagonia Torres Del Paine region, the Sarmiento and Amarga lakes are located in an area of glacial regression, which represents an environment with recent microbialite formation in a cold and arid climate. Additionally, in this cold, arid region, Lake Pali Aike, situated in the crater of a dormant volcano, is potentially an interesting case study. Each of these three different regions is characterized by extreme environmental conditions, such as a desert climate with high temperatures during the day and very low temperatures at night, strong winds, and a high incidence of solar radiation. The primary goal of integrating studies of these three distinctly diverse environments located in varying geological settings is to develop an actualistic facies model representing the ancient conditions of the various Pre-Salt lacustrine depositional environments, ranging from deep subaqueous, intermediate subaqueous, shallow subaqueous, and subaerial systems.

Petrographic Image Classification Based on Convolutional Neural Networks: A Case Study with the Unconventional Carbonates of the Brazilian Pre-Salt Play

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Machine learning (ML) algorithms have become widely applied in different areas of geosciences, for a great diversity of tasks such as data conditioning and processing, resolution improvement, image classification among many others. The application of ML allows to analyse large amounts of data, identify complex patterns or correlations, and might save time, reducing costs when compared to conventional approaches. Among ML techniques, Convolutional Neural Network (CNN) proved to be useful in several geosciences studies but mainly as a powerful tool for image classification. In the context, of the carbonate reservoirs of the Brazilian Pre-salt play, the sedimentological complexity of such deposits allied with the large amount of data being produced stimulate the use of automatic image classification approaches. Several recent works have explored the potential of different ML methods, including CNN, for petrographic image analysis considering many different geological settings and research purposes. However, only few studies were developed specifically targeting samples from the Brazilian Pre-salt reservoirs. In this work, we report the preliminary results of petrographic image classification of thin sections from the Aptian Barra Velha Formation carbonates from Santos Basin, Brazil. We explored the potential of CNN for facies prediction considering a three-level classification based on facies upscaling, including a simple one with 5 classes, and intermediate with 9 and a complete with 23 classes. The initial data base of 740 high resolution scan images (6400 dpi) of complete thin sections (both plane and crossed polarized) is constantly growing as samples from new wells are being added, and, for each increment of database, the model is retrained. The preliminary results indicated an accuracy in facies prediction of 89% for the simple classification, with a weighted and average f1 score of 0.92 and 0.72, respectively. This work is expected to develop a reliable method for automatic petrographic image classification favouring fast database building in the challenging exploratory settings of the Brazilian Pre-Salt play.

Soft-sediment deformation structures and sedimentary dykes in a dolomitized carbonate platform: evidence for an earthquake-related origin ("carbonate seismites", Norian, Dolomia Principale, Southern Alps, Italy)

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The interpretation of the genetic process responsible for the development of soft-sediment deformations structures, common in siliciclastic deposits and less abundant in carbonate successions, is complex, as different processes may produce similar structures. The interpretation of the origin of these structures may benefit, beside a detailed sedimentological study, from the deep knowledge of the regional context, that can provide hints on the processes active at the time of deposition of the studied successions. The interpretation of soft-sediment deformation structures as consequence of seismic shocks is important for paleoseismology studies, nevertheless, the interpretation of these structures as "seismites" requires a detailed sedimentological study and the reconstruction of a detailed geological setting by field work. The occurrence of multiple soft-sediment deformation structures in a fault-controlled basin preserved in the different subenvironments of a Norian carbonate system in the Southern Alps of Italy (presence of pseudonodules in basinal resedimented limestone, sedimentary dykes and clinostratified breccias with unlithified clasts in slope settings and liquefaction of inner platform facies at the platform top) testify to an origin related to multiple seismic shocks affecting the studied carbonate stratigraphic succession. The detailed sedimentological study framed in a geological setting characterized by syndepositional tectonics responsible for the development of intraplatform basins allowed for the characterization of different types of deformation structures. All these structures, albeit different in different types of sediments, are compatible with multiple occurrences of seismic shocks, also affecting repetitively the same stratigraphic intervals. The different types of soft-sediment deformation structures in the studied carbonate system provide a rich catalogue of different structures related to seismic shocks, representing a possible reference for other similar settings.

Fracture Characterization Using Seismic Attributes in Pre-Salt Carbonate Deposits: Barra Velha Formation, Santos Basin, SE Brazil

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The Brazilian pre-salt reservoir of the Barra Velha Formation (Aptian) in the Santos Basin is composed of a set of highly heterogeneous naturally fractured carbonate rocks, whose main facies correspond to fascicular calcite crusts (shrubstones) intercalated with grainstones and rudstones, and layers rich in magnesian silicates containing calcite spherulites.

Characterizing faults and fractures is a matter of great practical importance for hydrocarbon recovery since they provide a major control on the fluid flow within carbonate reservoirs. For the Barra Velha Formation, the understanding of faults and fractures is particularly important since it contains areas of high natural fracture intensity associated with vugs, which are responsible for enhanced production rates. Vuggy and fractured areas are linked to different depositional facies including shrubstone and spherulite facies with high dolomite content.

In modern interpretation, seismic attributes have proved to be an effective approach for detecting faults and fractures below the resolution of conventional seismic data, especially in areas where little to no image-based logs are available, providing a time-efficient and cost-effective aid to traditional methods. Key attributes often used include dip-magnitude, dip-azimuth, coherence, volumetric curvature, and ant tracking.

In this study, we conduct seismic analyses of naturally fractured areas of the Barra Velha Formation, with the use of mostly structural seismic attributes to provide fracture information throughout in the region of interest in terms of density, length, and orientation, using a 3-D post-stack time migrated seismic volume integrated with well data. However, the illumination and resolution in the pre-salt section of the seismic volume present challenges to the application of this seismic-based workflow.

Through edge-enhancing seismic attributes, we identify three fault families with E-W, NNW-SSE, and NNE-SSW orientations, corresponding to the main tectonic pulses in the study area. Comparison of fracture densities from image logs and seismic data shows coincidental areas with intervals of high fracture density at both scales. Preliminary results also show a good correlation between the fractures identified on the log image data with fractures extracted automatically from seismic attribute volumes.

Geochemical evidence of shallow-water hydrothermal venting in a lower Albian carbonate ramp (Basque-Cantabrian Basin, W Pyrenees)

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In the Basque-Cantabrian Basin (western Pyrenees, northern Iberia), a lower Albian synrift carbonate succession of the Ramales platform records the transition from a shallow-water carbonate ramp composed of echinoderm-dominated carbonate facies to a shallow-water micritic ramp dominated by microbialites with planktonic foraminifera and nektonic fauna. Synsedimentary extensional faults controlled the morphology of the ramp. In the Agüera sector of the Ramales platform, the micritic ramp shows pseudokarst or irregular geometries embedded in calcarenite facies, which are filled with micrite and large sparry calcite (up to 10 cm). Petrological analysis shows alternating peloidal micrite and sub-mm sparry calcite layers in the infills, indicating their coeval sedimentation/precipitation at very shallow depths. In addition, the presence of channel-like structures filled with microdolomite breccia and microcrystalline silica indicate synsedimentary to eodiagenetic Mg- and silica-rich fluid-rock interaction. Multiple geochemical analyses in different nearby sectors of the studied Ramales platform have been carried out. The $\delta^{13}C$ and $\delta^{18}O$ values indicate similar ratios for the calcarenite and micrite facies of all sectors of the ramp, with the exception of the large sparry calcite and channel-filling dolomite in Agüera, which show more negative values, and are interpreted as hydrothermal. Strontium isotopic analyses in all sector samples indicate $^{87}Sr/^{86}Sr$ ratios higher than the expected Albian seawater and are interpreted as the signature of deeper, radiogenic fluids. The studied samples show REE+Y patterns, Ce negative and La positive anomalies, and Y/Ho ratios suggesting seawater signatures. However, Eu positive anomalies are observed in the large sparry calcite of the Agüera sector. Trace element analysis shows a general enrichment in Sr, Zn and As with respect to seawater. Thus, petrological and geochemical data evidence the synsedimentary interaction of seawater and diagenetic fluids. These fluids reached the seafloor through the permeable active synsedimentary faults, induced the formation of the pseudokarst and channel-like features and could have impacted on the ramp ecosystems inducing micrite precipitation on the rest of the carbonate ramp.

Neogene cold-seep microbial carbonates (Crotone Basin-South Italy)

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For the first time, the Neogene cold seep carbonate deposits of the Crotone Basin (south Italy) are described. These deposits form a carbonate body reaching a maximum length of 350 m and a thickness 40 m and are characterized by a conduit facies made of authigenic carbonates filling the previously active gas/fluid escape pipes. In addition, a pavement facies is observed, which consists of early carbonate-cemented bioclastic and siliciclastic sediments commonly colonized by a chemosynthetic macrofauna dominated by articulated and in life-position Lucinids bivalves. The conduit facies is characterized by the inward accretion of dark micritic laminae alternating with clear crystalline layers. The micritic laminae show a microbial peloidal to dendrolitic fabric, which commonly incorporates planktonic foraminifera and coprolites. These contrast with the crystalline layers, which are characterized by microspar laminae and sparry crusts made of prismatic zoned calcite crystals. The pavement facies is characterized by laminated microbial boundstones, bioclastic bearing micrite, foraminiferal oozes and hybrid arenites. The foraminiferal assemblage is characterized exclusively by planktonic forms, which - together with the relative proportion of sandy/silty grains - suggests a deep-water setting with occasional siliciclastic coarser sedimentary flows. The pavement facies shows common brecciation features, possibly indicating the establishment of post-depositional overpressure conditions due to gas/fluid injection. Clasts of breccias show overgrowth by primary fibrous to acicular isopachous to fan-shaped calcite cement. Stable Isotopes analysis of all the studied facies reveals negative $\delta^{13}C$ values (-6.82 to -37.39 ‰) and relatively positive $\delta^{18}O$ values (-0.04 to 3.39 ‰), most probably indicating the presence of a complex mixture of methane with other hydrocarbons and the destabilization of gas hydrates and/or dehydration of clay minerals.

Some issues on carbonate factories of Upper Miocene Lithothamnion Limestone (Majella central Apennines, central Mediterranean)

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The concept of carbonate factory is certainly a fundamental point for carbonate sedimentology, A key aspect that arose those years was the individuality or multiplicity of the carbonate factory within carbonate platforms. The *Lithothamnion* Limestone lithostratigraphic unit cropping out in the Maiella Mountain (Central Apennines), offers the possibility to analyse the coexistence of different styles of carbonate production. This lithostratigraphic unit, late Tortonian to early Messinian in age, constitutes the uppermost, shallow-water unit of the Bolognano Formation. The Maiella Mountain represents the northern extension of the Apulia Carbonate Platform developed in the Adriatic domain of the central Mediterranean area. The profile of the *Lithothamnion* Limestone is consistent with a homoclinal carbonate ramp, with a wide middle ramp environment in which coralline algae, mainly forming the mäerl facies, dominated the carbonate production. The outer ramp, in the aphotic zone, was characterized by bioturbated hemipelagic marls with planktonic foraminifera and pectinids. The inner ramp was widely colonized by seagrass meadows interfingering with the mäerl facies of the middle ramp. The main biota producing carbonate sediments of this vegetated area were benthic foraminifers (mainly porcelaneous) and red algae (RA-Foralgal) together with abundant serpulids. The shallowest facies of the inner ramp consist of oolitic shoals and coral buildups generally encrusted by serpulids and red algae. One of the classical carbonate factory classifications is based on the style of carbonate precipitation: abiotic, biotically induced and biotically controlled with heterotrophic and autotrophic modes. This resulted in three main types of carbonate factories: the tropical shallow-water factory (T-factory), dominated by light-dependent biota (biotically controlled); the cool water (C-factory), dominated by heterotrophic skeletal production (biotically controlled) and the mud-mound (M-factory), with predominant microbial and abiotic precipitates (biotically induced and abiotic). Following this classification, two carbonate factories coexist in the *Lithothamnion* Limestone, the T-factory in the shallow inner ramp and the C-factory in the middle and outer ramp. Classically, the co-occurrence of the T-factory (dominated by a photozoan skeletal assemblage) and the C-factory (dominated by a heterozoan skeletal assemblage) has been interpreted to represent sedimentation in the warm-temperate realm, in a wide range of trophic conditions. However, the inner ramp of the investigated example shows also ooid deposits, typically considered exclusive components of the T-Factory developed in a tropical belt. In this work, we will try to justify or disprove the coexistence of tropical and cool water carbonate components and to understand which environmental and climate conditions characterized the paleo-Adriatic seawater between late Tortonian and early Messinian.

Were we too quick to discount Mixing Zone Dolomitization? An insight into the Dolomitization of the Arab Formation

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The Jurassic Arab Formation, which extends over large portions of the Arabian Gulf, is considered to be one of the largest oil and gas reservoirs in the world. Despite its importance, detailed diagenetic studies linking petrographic and geochemical data to the depositional facies and sequence-stratigraphic frameworks are limited. Within the Arab C and Arab D members, compartmentalised and laterally heterogenous dolomitised reservoir zones host enhanced reservoir quality in comparison to their undolomitized counterparts. Their formation is interpreted to be multi-phase, with two main dolomitization styles observed (fabric destructive and fabric retentive), both with a strata-bound distribution. Current models for dolomitization in the Arab invoke sabkha and reflux models, however there is not a completely unified consensus for their formation.

This study presents new evidence for the refinement of the Arab dolomitization models in the context of the vertical and lateral distribution of the different types of dolomite within the study field. It is based on the detailed petrographic characterisation of 528 thin sections, and a subset of stable isotope analysis (carbon and oxygen) of cored Arab C and Arab D members from 3 wells in offshore Abu Dhabi, United Arab Emirates. Interpretation of log signatures has extended the study to the uncored intervals, as well as a further 3 uncored wells in the study field.

Results reveal that the fabric destructive dolomitization, formed of non-planar to planar-s non-ferroan dolomite, with only microbial laminations locally preserved, is the most common style of dolomitization observed in both the Arab C and Arab D members. It occurs dominantly within the proximal supratidal and intertidal mudstones and wackestones, with dolomitization likely happening in an evaporitic sabkha setting. Fabric retentive dolomitization, characterised by planar-e to planar-s non-ferroan dolomite is more limited and observed only within the moderate to high-energy inner ramp grainstones to pack-grainstones of discrete reservoir zones, where both allochems and earlier formed marine calcite cements are pervasively replaced. Whilst safer to interpret as the result of seepage reflux of lagoon brines during relative sea level fall, this study presents evidence opening up a discussion for its formation through mixing zone dolomitizations, challenging the *status-quo*.

Messy migrating mosaics: a numerical forward modelling analysis of carbonate stacking and bed thickness distributions

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Data from modern shallow-water carbonate depositional systems indicate a complex spatial arrangement of sediment on platform tops, with little or no quantifiable relationship between sediment type across a water depth range of ~10m, and large areas of non-deposition covering more than 20% of sea floor area. These observed distributions of modern carbonate sediment are often referred to as a facies mosaic, and contrast markedly with some other models where simpler, essentially linear facies belts migrate under strong control of relative sea-level oscillations. Output from two numerical models, one with accommodation-controlled linear facies belts, and one with a shallow-water facies mosaic, produce vertical sections that can be compared with outcrop vertical sections to determine which of these two end-member models produces a better match.

Quantitative comparison indicates the facies mosaic model produces a better match with observed outcrop lithofacies thickness distributions, as well as much lower quantitative measures of facies and layer thickness order, also more consistent with observations from outcrop. These results have several important implications, most notably that many interpretations of outcrop carbonate strata as the product of simple linear facies belts migrating under simple accommodation control are probably unrealistic. Such misinterpretation may also explain why many outcrop studies invoke cyclical strata without sufficient quantitative evidence to justify that interpretation. More robust use of quantitative methods to test for the presence of order in strata, and a move away from these “modelling in disguise” interpretations of outcrop strata would perhaps be sensible.

Carbonate veins (banded travertine) in geothermal depositional systems: the sedimentary evidence of tectonic activity

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Brittle deformation at shallow crustal levels guarantees the dynamically or kinematically maintained permeability through time in fault zones permeated by hydrothermal fluids. The high encrusting capacity of these fluids, coupled with CO_2 rapid degassing, leads to fluid supersaturation and subsequent crystallisation of Ca-carbonate. The Ca-carbonate deposition tends to reduce the permeability through the progressive sealing of the fractures which remain sealed until a new tectonic pulse favouring the restoration of the permeability. The neologism "travitonic" fixes the concept that travertine deposition and tectonic activity are inseparable processes. In this view, the Ca-carbonate banded veins and travertine deposits testifies the sedimentary response to tectonics and possibly seismic events. The analyses of the tiny-laminated Ca-carbonate banded veins evidence the iterate cycles of fracture opening followed by periods of deposition. Geochemical-fluid inclusion analyses highlight the characteristics of the circulating fluids and that, coupled with possibility to perform radiometric dating, allow to reconstruct the palaeoseismicity in fossil geothermal systems. These deposits resemble as one of the best targets in depicting the tectonic activity in geothermal areas.

Mercury and phosphorus fluctuations across the Oceanic Anoxic Event-2 in the Tethyan shallow water carbonate platforms

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The Cenomanian–Turonian Oceanic Anoxic Event 2 (ca. 94 Ma; OAE-2) represents one of the largest short-term perturbations of the global carbon cycle, associated with extensive deposition of organic carbon-rich levels (black shales) in ocean basins around the world, and with major changes in geochemical cycles and biological turnovers. Several triggering mechanisms have been proposed, ranging from increased oceanic/atmospheric pCO_2 resulting from the emplacement of large igneous provinces (LIP) to increased nutrient inputs to surface waters from continental sources. Volcanoes are a primary source of mercury (Hg) to the global oceanic-atmospheric system. Recently, analyses of mercury concentration recorded in cretaceous carbonates have shown to be a robust proxy for ancient volcanic episodes.
On the other hand, an intensified hydrological cycle and a consequent increase in continental weathering is thought to have fueled the high marine primary productivity associated to the deposition of black shales at many locations during the OAE-2. Among the essential nutrients for primary productivity, phosphorus (P) is of particular interest, given its role as a limiting nutrient on geologic time scale.
To date, most of the geochemical Hg and P data dealing with OAE-2 come from deep-water carbonate successions, whereas the shallow-water carbonate counterparts have been much less investigated. Furthermore, detailed P and Hg concentration records encompassing the entire OAE-2 interval are scarce.
Here, we present new Hg and P analyses, together with sedimentological and stable isotopes (C and O) data, from well-exposed Tethyan shallow water carbonates sections, across the OAE-2. Biostratigraphy and carbon-isotope stratigraphy were used to establish a precise stratigraphic framework and for high-resolution correlations. Results show that all platforms experienced significant Hg and P variations, which can be correlated among the different locations. A marked positive shift in concentrations of both elements is observed straggling the onset of OAE-2. Finally, the high-resolution stratigraphic framework established in this study allowed to compare shallow water record with the deep marine one providing important insights for understanding how global environmental and oceanographic perturbations caused by OAE-2 affected shallow-water settings and at which temporal scale.

Brachiopod-rich mud mounds from Derbyshire, UK: exception or rule in the Mississippian?

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Brachiopod-rich mud mounds occur in the upper Visean (Brigantian) Monsal Dale Limestone Formation of the Derbyshire Carbonate Platform, UK. They developed at the top of the formation in various platform interior, intraplatform ramp and platform margin settings. The mud mounds are lens-shaped buildups with a diameter of 300-500 m and a thickness of 30-50 m. The massive core of the mud mounds consists of clotted peloidal micrite (automicrite) and fenestellid bryozoan boundstone with calcite-replaced siliceous sponge spicules, whereas laterally-equivalent inclined flank beds consist of brachiopod–bryozoan–crinoid packstone. The mud mounds developed during an event of accommodation creation likely related to glacioeustatic fluctuations at the initiation of the Serpukhovian–middle Bashkirian glacial period of the Late Palaeozoic Ice Age (LPIA).

Brachiopods are abundant and diverse in every lithofacies of the mud mounds and are not, as previously thought, limited to storm-scoured "pockets" in the mud mound complex core. The upper Visean Derbyshire mud mounds are representatives of a newly defined fenestellid bryozoan–brachiopod–siliceous sponge mud mound category, occurring in various middle–upper Visean Western European sites. Other brachiopod rich mud mounds and reefs occur in the middle–upper Visean and developed below fair-weather wave base in carbonate platform settings. It was probably a combination of relative shallow depths between fair-weather and storm wave base, moderate-energy, diverse substrate types, and distribution of food resources which favoured the brachiopod colonisation and in turn the structuring of brachiopod-rich buildups in the middle–upper Visean.

Silicification patterns in lacustrine Pre-Salt carbonates from Santos Basin, Brazil

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The vast Pre-salt carbonate reservoirs of offshore eastern Brazil produce approximately 75% of the country hydrocarbons. Silicification is a key process that affected these unique deposits that occur in basins both sides of the South Atlantic, leading to significant changes in the quality of Pre-salt reservoirs and even erasing their original texture and composition in some cases. In the Aptian Pre-salt section of Santos Basin, silicification has been attributed to a variety of processes, from the freshening of lake waters to hydrothermalism. Yet, the distribution and controls on the silicification is not well understood. A detailed petrographic analysis of intensely silicified samples from 3 cored wells from central Santos Basin showed that there are differences between the silicification of still recognizable *in situ* deposits, originally composed of magnesian clay matrix and calcite fascicular shrubs and spherulites, and the originally more porous reworked intraclastic deposits. Cryptocrystalline silica and microcrystalline quartz represent the main types of silica in the *in situ* deposits, and occur mostly replacing the clay matrix. Micro- and macrocrystalline quartz, and fibrous and spherulitic chalcedony commonly cemented matrix dissolution pores in these samples. In particular, mm to cm thick laminae of chert are mostly devoid of features suggestive of precursor calcite shrubs and spherulites, but commonly contain articulated ostracods and lamination remnants. This implies an early replacement of likely originally mudstones that was at times related to suppression of calcite precipitation. The clay matrix therefore appears to be the main substrate for the early precipitation of fine-crystalline silica minerals, either directly from the lacustrine waters or from modified eodiagenetic fluids. The metastable nature of magnesian clays likely facilitated the process, as its dissolution during early and burial diagenesis represents an important source of silica. Additionally, the organic content of the matrix may have contributed to silica precipitation. Partial silicification of calcite spherulites and shrubs in some of the *in situ* samples in which Mg-clay was dissolved or dolomitized appears to be linked to related clay peloids engulfed in the aggregates, which nucleated the precipitation of microcrystalline quartz. Similarly, microcrystalline quartz preferentially replaced mud intraclasts in some reworked samples. In these intraclastic deposits, micro- and macrocrystalline quartz, prismatic drusiform quartz, and fibrous chalcedony occur as common cements, decreasing their reservoir quality. Finally, extensive silicification of the carbonate aggregates and intraclasts is more common where associated with prominent hydrothermal features, such as replacive blocky pyrite, barite cement, and intense fracturing, and was responsible for significantly erasing their primary textures and composition, strongly reducing primary and matrix-dissolution porosity.

Microbial diversity of Biogenic textures in the Paleogene Ahuichila Formation, northeastern Mexico

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Microbial communities are the oldest paleontological evidence of life on Earth preserved as organosedimentary rocks known as microbialites, but also as sedimentary structures built under microbial influences known as Microbially-induced sedimentary structures or MISS. The Ahuichila Formation clearly exposes diverse primary sedimentary textures and structures that are interpreted as microbially-induced. The Ahuichila Formation has been described as a siliciclastic deposit dominated by conglomerates deposited with different subordinated lithologies, mainly lacustrine carbonates, but also as sandstones, shales and less frequently, evaporites. For decades, the interpretation, age and stratigraphic range of the Ahuichila Formation was a debatable issue, but recent studies confirms its Paleogene age. Among the wide range of microbial textures, finely-laminated mats and stromatolitic growths outstand as the most representative textures preserved in outcrops from the state of Coahuila, Zacatecas and Durango in northern Mexico. This work presents characteristic structures from Ahuichila: (1) corrugated amorphous structures, (2) alternated biolaminites, (3) botryoidal textures, (4) stromatolitic textures and (5) irregular pillow microbial growths. These structures show distinctive patterns and facies associations that are key for paleoenvironmental reconstruction. To what extend such microbial textures may reflect paleoenvironmental conditions and biological control is here discussed.

Carbonate carbon isotope and trace elements indicate the Cambrian paleoenvironment, paleoproductivity and organic matter development in the western margin of Ordos Basin, China

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The western margin of the Ordos Basin in China developed relatively complete and thick Cambrian deposits, mainly carbonate deposits. The TOC test of carbonate samples from the Cambrian section of the Qinglongshan Getanggou section in the western margin of the basin shows that the TOC of carbonate samples is generally very low, with an average of 0.02 % (n=108). Based on the carbonate inorganic carbon isotope δ^{13}Ccarb and organic carbon isotope δ^{13}Corg, combined with the redox indicators U/Th, δU, Mo-EF/U-EF and paleosalinity indicators Sr/Ba, B/Ga, and paleoproductivity indicators Babio and Cubio, the characteristics of Cambrian organic matter development and the reasons for low TOC in the western margin of the basin were systematically studied. The linear correlation analysis of carbonate δ^{13}Ccarb and δ^{18}Ocarb shows that there is no correlation between them (R2=0.17, n=114), which proves that carbonate δ^{13}Ccarb basically retains the paleoproductivity and sedimentary environment information of the primitive ocean. The δ^{13}Ccarb and paleoproductivity indicators Babio and Cubio show that the paleoproductivity of the late Cambrian is higher than that of the early Cambrian and middle Cambrian, but the redox index and salinity index show that the sedimentary environment with higher salinity and stronger reducibility is conducive to the preservation of organic matter. At the same time, the overall low TOC of Cambrian carbonate in the western margin of Ordos Basin may be related to the large Dissolved Organic Carbon Pool (DOCP) in the Cambrian ocean at that time. Refractory Dissolved Organic Carbon (RDOC) is abundant in seawater, but it is not easy to be deposited in carbonate.

Automated classification of dissolved zones in acoustic borehole image logs: An example from Brazilian pre-salt carbonate reservoirs

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The occurrence of dissolved features in carbonate rocks is very common and may varies from vuggy millimetric pores, enlarged conduits and fractures to caves that are visible in the seismic section. Their occurrence and distribution vary according to the structural and stratigraphical evolution of the basin which leads to a high heterogeneity. In this way, predicting dissolved zones in carbonate reservoir is important due to its capacity to conduct fluids, in addition to helping the drilling campaign to predict zones with high losses of drilling mud.
In the Santos Basin - Brazil, the Barra Velha Formation is composed by lacustrine carbonates, and considered highly heterogeneous due to distinct diagenetic phases that controls the petrophysical parameters. In some areas, the high dissolution of carbonates rocks produces a heterogenous system of vuggy pores and caves, contributing to high performance production. This may be related with karstification processes that can be widespread in some parts of the basin. However, the identification of karstic features in the pre-salt reservoirs is a hard task, once the seismic resolution is generally low (~40m). To solve this problem, through the analysis of borehole image logs (BHI) it is possible to identify the main dissolved zones and predict at well scale, the main distribution of vuggy pores, fractures and caves/well developed karst.
This work proposes a workflow to predict the occurrence of dissolved zones through the use of acoustic borehole image logs using a deep learning technique called Convolutional Neural Network (CNN). CNN is a computational artificial network applied for computer vision such as image classification, object detection, segmentation, among others. Here, acoustic BHI were interpreted into six classes according to the degree of dissolution where (1) is the non-dissolved carbonate rock and (6) is the well-developed karst. The intermediate (1) and (2) are the vuggy matrix and (3) and (4) vuggy fracture classes, varying their degree of dissolution from incipient to high. Two wells were used in this workflow, the image was cropped in each 10cm (vertical) with resolution of 1:10 and subsequently classified. A total of 1870 images were extracted, and 1496 of them were used for training and 375 for testing. The first results show an overall accuracy of 0.75. It is expected that this workflow improves the identification of dissolved zones and help the decision-making process for oil production and water and gas injection in a field.

Biomacromolecules increase diagenetic isotope exchange in biocalcites

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Recent experimental work demonstrates that both abiotic and biogenic calcites rapidly exchange oxygen isotopes with surrounding fluids at low temperatures without any evidence of overt morphological changes. In particular, marine biocalcites experience more rapid exchange than abiotic calcites, which has profound implications for paleoclimate reconstructions. The reason behind this rapid exchange is not yet known; however, calcitic skeletons of foraminifera, bivalves, brachiopods, and corals are rich in organic compounds and composed of sub-spherical calcium carbonate nanogranules 40–150 nm in diameter, which represent huge surface areas on which diagenetic fluids can act. In our previous work[3] we used ^{18}O-enriched artificial seawaters in controlled experiments to simulate the effects of fluid-mediated diagenesis on foraminifera tests. Although, the three studied species of foraminifera were composed of similar-sized nanogranules, we observed significant differences in the amount of oxygen isotope exchange, which we attributed to species-specific variations in the amount and structure of organo-mineral interfaces. To investigate the influence of biomacromolecules on diagenetic isotope exchange we expand our work to include bivalves, brachiopods and fossil foraminifera skeletons composed of similarly sized nanograins but with vastly different microstructural architectures and organic contents. We use photo-induced force microscopy (PiFM), a new cutting-edge technique to chemically fingerprint and map the most diagenetically relevant biomacromolecules. Additionally, by 'roasting' biocalcites in an oxygen atmosphere prior to incubation to remove most organic compounds, we find that exchange rates are greatly enhanced when the organic fraction is present.

Petrographic and trace elements characterization of diagenetic carbonates associated with MVT mineralization (lower Carnian, Lombardy Basin, N Italy)

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The petrographic, geochemical and trace elements characterization of the diagenetic calcite and dolomite phases associated with Mississippi Valley Type (MVT) deposits can contribute to a better understanding of the fluids responsible for the mineralization. The lower Carnian Breno Formation (BRE) and Calcare Metallifero Bergamasco (CMB) in Dossena (Lombardy Basin, Southern Alps) are two shallow-water peritidal carbonate lithostratigraphic units hosting sphalerite (ZnS), galena (PbS) and fluorite (CaF_2) MVT mineralization. The identified diagenetic phases in the BRE paragenetic sequence are: 1) Cal0 intra-bioclastic packstone-wackestone constituting the host rock ($\delta^{13}C$=0.9‰ V-PDB; $\delta^{18}O$=-6.3‰ V-PDB), 2) Dol1 fracture filling saddle dolomite cement ($\delta^{13}C$=1.1‰; $\delta^{18}O$=-10.9‰), 3) Cal2 fracture and void filling blocky calcite cement ($\delta^{13}C$=1.1‰; $\delta^{18}O$=-7.5‰), 4) CaF_2, 5) Cal3 sparite cement filling intercrystalline voids between Dol1 crystals. The CMB paragenetic sequence includes: 1) Cal0 bio-intraclastic packstone-grainstone ($\delta^{13}C$=0.6‰; $\delta^{18}O$=-11.9‰), 2) Dol2 fracture filling saddle dolomite cement ($\delta^{13}C$=0.7‰; $\delta^{18}O$=-11.3‰), 3) Cal4 fracture and void filling blocky sparite cement ($\delta^{13}C$=0.6‰; $\delta^{18}O$=-8.3‰), 4) ZnS-PbS-CaF_2, 5) Cal5 sparite cement filling intercrystalline voids between Dol2 crystals. $\delta^{13}C$ values of both the BRE and CMB diagenetic phases fit the range of expected values for Middle-Upper Triassic pristine marine carbonates, while the low $\delta^{18}O$ values suggest diagenetic alteration by high temperature fluids. Shale-normalized $REE+Y_{(SN)}$ concentrations of the BRE diagenetic phases reveal: 1) flat pattern for Cal0 host rock indicative of siliciclastic contamination, 2) convex-concave pattern for Dol1 with positive Y anomaly, likely from hydrothermal fluids, 3) bell-shaped pattern for Cal2 enriched in MREEs (coeval with CaF_2) with positive Eu and Y and negative Ce anomalies, suggesting precipitation by low temperature (<200°C) hydrothermal fluids, 4) depleted pattern in HREEs of Cal3 (post CaF_2) with positive Eu, Y and Gd anomalies possibly because of precipitation from hydrothermal fluids. $REE+Y_{(SN)}$ patterns of the CMB diagenetic phases are: 1) flat for Cal0 (host rock) because of siliciclastic contamination, 2) convex-concave for Dol2 with Eu and Y anomalies from hydrothermal fluids, 3) depletion in HREEs for Cal4 (coeval with ZnS-PbS-CaF_2) with a weak positive Eu anomaly, possibly precipitated by hydrothermal fluids, 4) weakly depleted HREEs for Cal5 (post ZnS-PbS-CaF_2) with positive Eu and Y anomalies, interpretable as precipitated by low temperature hydrothermal fluids, which have interacted with the host rock. In the CMB, Cal4 cement crosscut stylolites, allowing to set the emplacement of the mineralization in burial conditions following pressure solution. This study provides some preliminary information about the features of the fluids involved in the precipitation of carbonates associated with MVT deposits: both host rocks result contaminated by siliciclastic input, while the diagenetic phases preceding and following the MVT mineralization seem to be precipitated by low temperature hydrothermal fluids.

Piambo fossil travertine field: Witnessing basin scale events and drawing paleolandscapes in the Namibe Basin, Angola

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The Piambo field is one of the most preserved travertine fields of Lower Cretaceous Cangolo Formation, onshore Namibe basin, Angola. The deposits were formed atop ~ 134 Ma Bero volcanics associated with the South Atlantic rifting. The carbonate facies look to be arranged in the original position, allowing to recognition of fabrics indicating paleoenvironments like geysers, cascades, and pools. The diversity of facies is interpreted as a result of the relative location with respect to the spring proximity, together with variations in topography and water flow under subaerial conditions.

The distribution of the deposits linked to a structural control suggests the relation of hydrothermal fluids to N45-60W transtensional structures, creating a set of subsidiary normal-tilted blocks observed in Bero Volcanic rocks, composing an active tectonic scenario in this local.

The petrography, mineralogical analyses by X-ray diffractometry, and C&O isotopes suggest records of early diagenetic events, which include neomorphism, early cementation, karstification, silicification, and calcretization. The understanding of these features could bring new information to the geochemical modelling for the major basin-scale tectonic processes, as an ancient travertine field can provide paleogeographic insights into carbonate sources for the Aptian lacustrine successions in the early stages of the South Atlantic evolutionary history.

Carbonate sedimentary environments in the epicontinental Baltic Devonian basin: Pļaviņas Formation, Lower Frasnian

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This study focuses on detailed facies analysis of the Pļaviņas Formation (Fm), Upper Devonian, Frasnia, and interpretation of their sedimentary environment. The study area is north-western part of the Main Devonian Field (also Baltic Devonian basin or BDB), including the territory of Latvia and south-eastern Estonian.

The Upper Devonian section is represented by various siliciclastic deposits, dolomites, their transitional varieties, but some parts of the section contain gypsum deposits as well. The sedimentary environments of the Late Devonian siliciclastic deposits in last years were studied rather widely, but there was much less focus on the carbonate rocks, with exception of study by Kleesment et al. (2013). The territory of Latvia was not covered in these studies at all.

In this study thirteen (13) facies were divided. They are united into five (5) facies associations: thin layered dolomites/laminites, carbonate rocks with organism remains and oolites, carbonate rocks with clastic material and lithoclasts, carbonate rocks with signs of subaerial exposure, clayey carbonate rocks.

It was concluded that connection with ocean was to south-west from Baltic palaeobasin central part. It is worth mentioning that carbonate rock composition, structures, textures and organism complexes suggests that in Pļaviņas time, this part of basin was epicontinental platform and its X zonewas towards north-east.

The deposits of the Pļaviņas Fm in the Baltic palaeobasin formed in shallow-water, subtidal to intertidal regime. Typical association of gastropods, brachiopods, and stromatoporoids indicate the presence of normal-salinity seawater.

Previous studies and current study resulted in conclusion that the Baltic Devonian basin during the beginning of Frasnian was related to ocean to the south-west.

However, the carbonate rock composition, structures, textures, and organism associations suggest that in Pļaviņas time this part of basin was epicontinental platform and its X zone was towards north-east.

Facies vs diagenetic control on Upper Jurassic-Lower Cretaceous carbonate reservoirs in the subsurface of the Arabian Gulf

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Reservoir properties in carbonates are the result of the combined controls exerted by the depositional facies and the diagenetic history. Whether the facies or diagenesis, the understanding of the major controlling factor on porosity and permeability is paramount in hydrocarbon-bearing prospective areas. Knowledge of which control prevailed allows distributing them through space, with a significant impact on exploration and production. This contribution represents a case-study focused on two carbonate reservoirs of the Middle East, in the subsurface of the Arabian Gulf. Integrated stratigraphy, facies and diagenetic analysis allowed evaluating the principal controls on the reservoir properties of the Upper Jurassic Arab Formation and the Lower Cretaceous Sulaiy-Yamama Formations. The dataset included approximately 300 thin sections consisting of cuttings and, subordinately, cores recovered from 5 wells in the offshore of Bahrain. Porosity and permeability data were derived by core and well log analysis. The Arab Formation consists of superimposed evaporitic-carbonate couplets of Kimmeridgian-Tithonian age. It is lithologically and biostratigraphically constrained and subdivided into 4 members of regional extent (Arab D to A). The reservoir intervals correspond to the exclusively carbonate parts. The recorded microfacies types are indicative of shallow-water, inner neritic environments with episodic hypersaline sabkha conditions. The entire Arab succession is characterized by a variable limestone-dolostone ratio and suggests deposition ranging from tidal flat to shallow subtidal inner ramp settings, with also evidence of high-energy shoals. Textures are principally grain-supported. The good porosity (17%-28%) is primarily inter-particle or inter-crystalline, in the case of dolostones, and moldic and vuggy. The Arab Formation shows reservoir properties resulting from the interplay between depositional and post-depositional controls (i.e., carbonate dissolution). The Sulaiy Formation and the overlying Yamama Formation (Tithonian-?Hauterivian) consist of shallow-water limestones of relatively deeper neritic settings. Microfacies types are principally mud-supported and suggest deposition in low-energy subtidal settings that were episodically affected by fine-grained siliciclastic input. Occasionally grain-supported textures occur as well, indicating short-term high-energy events. The recorded facies are characterized by pressure-solution seams and stylolites, resulting from post-depositional mechanical-chemical compaction. Both the Sualiy Formation and the Yamama Formation include well-known reservoir intervals where the good porosities (10%-30%) are markedly controlled by the diagenetic overprint. Pervasively observed moldic, vuggy and fracture porosities (locally connected and associated with stylolites) are related indeed to carbonate dissolution of the otherwise tight mud-supported facies. The Arabian Plate paleogeography recorded a progressive switch in carbonate factories and geometries from the Late Jurassic to the Early Cretaceous. The Upper Jurassic carbonate

ramps were originally built by reservoir-prone facies which were positively affected by diagenesis. On the contrary, the Cretaceous reservoirs almost exclusively rely on post-depositional drivers, given the normally tight facies accumulated in the carbonate shelves and local basins of the time.

Environmental and tectonic controls on the Norian-Jurassic sedimentary succession in the Northern Calcareous Alps (Stumpfmauer, Austria)

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Western Tethys sedimentary successions are fundamental archives of Late Triassic to Early Jurassic environmental, climatic, biotic and tectonic changes. This study focusses on the Norian to Jurassic succession cropping out in the eastern Northern Calcareous Alps (Stumpfmauer, Austria). During the Late Triassic, the Northern Calcareous Alps belonged to the Western Tethys passive margin, characterized by the deposition of the early-dolomitized peritidal Hauptdolomit (Norian) adjacent basinward to the Dachstein carbonate shelf and passing upward to the mixed carbonate-siliciclastic Kössen Fm. (upper Norian-Rhaetian). This transition records the siliciclastic input from the European hinterland, reflecting a switch from arid to humid climate. The Kössen Fm., subdivided in the lower shallow-water Hochalm Mb. and the upper Eiberg Mb., accumulated in an intraplatform basin coeval to shallow-water carbonates (Upper Rhaetian Limestone). The Eiberg Basin and overlying Jurassic strata were extensively studied as a continuous marine record across the Triassic/Jurassic boundary. In contrast, shallow-water successions, time-equivalent to the Eiberg Mb. and Upper Rhaetian Limestone, located North of the Eiberg Basin, are poorly investigated.

The studied succession was divided in eight superimposed sedimentary units labelled from A to H, belonging to the Hochalm Mb. of the Kössen Fm. (Unit A peritidal cyclothems, Unit B claystone/marlstone with fossiliferous beds, Unit C coral boundstone to floatstone), Upper Rhaetian Limestone (Unit D subtidal cyclothems with claystone), Lower Jurassic shallow-water carbonate strata (Unit E ooidal coated grain peloidal grainstone with basal transgressive lag, Unit F bivalve-rich, microbialite and oncoidal lithofacies, attributed to the Upper Rhaetian Limestone in previous studies), Hettangian-Sinemurian Kalksburg Fm. (Unit G cross-laminated coated grain peloidal grainstone with quartz and chert) and Lower to Upper Jurassic Hierlatz Member, Adnet, Klaus and Ruhpolding formations indicative of the drowning of the carbonate shelf (Unit H red colour crinoidal packstone, thin-shelled bivalves packstone/rudstone with ammonites, hemipelagic radiolaria wackestone). Locally the succession is incomplete, with Unit A peritidal facies sharply overlain by Unit H hemipelagic limestone with a stratigraphic gap from late Norian to Middle Jurassic indicative of uplift and erosion of the shallow-water deposits before the Middle Jurassic drowning. This stratigraphic evolution is ascribed to the early-middle Jurassic extensional tectonics driven by the opening of the Alpine Tethys that controlled the formation of structural highs, where part of the Rhaetian succession was eroded. The identified sedimentary units can be framed in the evolution of Western Tethys and share similarities with depositional systems from the Western Carpathians, Transdanubian Range, Southern Alps and Dinarides suggesting coherent sedimentary responses and environmental, climate and tectonic controls in different palaeogeographic domains.

Carbon storage in carbonate reservoirs – Risks and opportunities in the context of different archetype reservoirs

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The frontrunner Carbon Capture & Storage (CCS) projects have been developed in clastic reservoirs with excellent reservoir properties and limited heterogeneity (e.g., Quest, Gorgon, Sleipner, In Salah). With increasing demand from industries and governments for decarbonization solutions, the attention is now moving also towards more complex storage reservoirs such as carbonate reservoirs. The main differences between carbonate and clastic systems in the context of CCS include the presence of the small-volume, high-permeability heterogeneities as well as the meta-stability of mineralogy with changing fluid composition, pressure & temperature. Both result in different behaviours with regards to flow and CO_2 plume architecture.

Carbonate reservoirs have the advantage that they are often large well-connected systems, ideal for long-range pressure dissipation with positive impact on storage efficiency. Fault compartmentalization is rare due to the non-sealing nature of faults in carbonates while the common presence of natural fractures enhances overall connectivity. However, the high degree of permeability heterogeneity may render plume predictability and hence CO_2 containment more difficult. Monitoring with geophysical approaches (4D seismic) may be challenging if high-permeability plumbing elements occur beyond seismic resolution (e.g., thin vuggy zones or fracture corridors). The reactivity of carbonates in the acidic environment of dissolved CO_2 brings both opportunity and risk. The reactivity can on the one hand support injectivity and create some limited additional pore space to increase the capacity, it can on the other hand jeopardize containment and well integrity. The common occurrence of more marly sediments as sealing lithologies in carbonate sediments poses another risk for containment.

The poster will present risks and opportunities for carbonate storage complexes in depleted fields and saline aquifers, providing handrails for geoscientists and reservoir engineers to screen and focus in on credible carbonate storage opportunities. The end-product will be two tables (for saline aquifer and depleted field settings) where the four technical pillars for CCS project evaluation in Shell (Injectivity, Capacity, Containment & Monitoring) are assessed in the context of carbonate reservoir heterogeneity archetypes. The tables will use an italian-flag approach to highlight risks and opportunities associated with different levels of heterogeneity in the reservoir and against the background of major processes that affect reservoir quality in carbonates (e.g., chemical compaction, dolomitization, diagenesis and fracturing).

Trona deposits as sedimentological analogues of Santos Basin Pre-Salt carbonates

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Pre-salt sedimentological cyclic pattern described in several cores, since the discovery of the Tupi Field in the Brazilian Santos Basin at the Petrobras Research Center, consists of beds of shrub-like crystals and diagenetic spherulites growing in magnesium clay matrix followed by laminites in a higher frequency deposition. Since then, a lot of research was carried out trying to find the perfect carbonate analogue for this kind of cycle in diverse places around the world, such as stromatolites from Shark Bay in Australia, travertines from Denizli Basin in Turkey or carbonate towers from Mono Lake in USA, but none of these analogues were the best fit for this proposal. Trying to advance on this theme, this work proposes that this kind of cycle is the same occurring in continental alkaline lakes, where evaporitic sediment patterns in endorheic basins, in a depositional framework of brine drawdown, are dominated by ephemeral salt pan hydrology. In such context, bedded salt crusts form a stack of subaqueous aligned crystal beds at the sediment-water interface; crystal grows diagenetically within saline and mud layers beneath the dry pan surface and finally laminated sediments are deposited. Such analogy has his best representation in trona deposits, sodium carbonate evaporites mainly occurring in continental arid regions containing contemporaneous volcanic deposits, mainly deposited in cycles constituted with grass-like trona, diagenetic trona displacive in mud/authigenic silicates followed by organic-rich laminated mudstone. The main occurrences worldwide are in the Wilkins Peak Member of Green River Formation (USA), Beypazari Mine (Turkey) and, recently, in Lake Magadi and Lake Bogoria (East African Rift). The reason for this unusual calcium carbonate depositional system, according to our interpretation, is the start of deposition in a sub-sea level basin fed by percolating hydrothermal marine waters through Walvis-Rio Grande volcanic barrier on Cretaceous times, in a basin with penecontemporaneous basaltic deposition. The geochemistry of alkaline lakes is decisively influenced by such rocks that provided to the lake Na^+ cations and HCO_3^- and CO_3^{2-} anions due to his lixiviation. In such context, pre-salt carbonates deposited as evaporitic deposits due to an unusual mixture of different brine compositions (calcium chloride brine plus sodium-carbonate brine), altering the chemical divided expected for alkaline lakes. Behaving as an evaporitic carbonate brine, the paleolake were submitted to intense aquifer base level fluctuation controlled by evaporation and tectonics, producing high frequency bedded cycles in the geological record. We enumerate the main points of analogy between trona and pre-salt carbonates (macroscopic and thin section descriptions) and the benefits to use such evaporitic analogue for more increased sedimentological models while also discuss the main differences between then and its impacts on the interpretation.

Is there an incompatibility between radiogenic strontium signal and a geochemical model derived from fluids interacted with basalts for Brazilian Pre-Salt carbonates of Santos Basin? Insights from an alternative proposition to explain such incompatibility through infiltration of marine waters in continental aquifers

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Rift tectonics between South American plate and African plate in Cretaceous allowed the possibility that the sag phase carbonates of the Santos basin were deposited as the initial/transitional stage of a closed sub-sea-level evaporite basin whose rising salinities culminated in the deposition of halite and bittern salts (carnallite, sylvite, tachyhydrite). Basinwide evaporites are singular events in the geological record. They form when a giant sub-sea-level basin becomes a sump of continental, marine and hydrothermal fluids, producing unexpected brine compositions in unusual depositional settings present in ancient evaporitic basins but absent from most modern ones. Integrating pre-salt carbonate deposition with the sedimentology, hydrology and geochemistry of ancient evaporitic basins, it is possible to propose a geochemical model for pre-salt carbonates in Santos Basin. Regarding the Walvis-Rio Grande volcanic high as a topographic barrier during the Aptian, we already suggest in previous work that the main sources of fluids to the Barra Velha paleolake were hydrothermal brines, mostly from infiltrating seawater that reacted at depth with the basalts of the volcanic barrier (hyperextension of the lithosphere, with a shallow Moho, increased geothermal gradients to levels favourable for the generation of hydrothermal $CaCl_2$ brines) and internally drained $NaHCO_3$-bearing alkaline waters, formed by physical/chemical weathering of penecontemporaneous basaltic rocks, saturating the paleolake in a hybrid brine composed calcium bicarbonate/carbonate, silica-gel and sodium chloride ($2NaHCO_3 + CaCl_2 = Ca(HCO_3)_2 + 2NaCl$). One puzzling aspect to confirm such geochemical model is the Sr radiogenic signal measured in pre-salt carbonates, that indicates a continental felsic source of fluids (0.713), incompatible with marine waters percolating in basalt as proposed. In this work we suggest an alternative interpretation for such radiogenic signal, indicating the increasing strontium isotopic ratio in fluids as a result of the infiltration of marine waters in continental aquifers, through base-exchange reactions between marine waters and typical cation exchangers in a shallow continental aquitard reservoir such as clay minerals, organic matter, oxyhydroxides and fine-grained rock materials. To prove this proposition, a geochemical modelling of base-exchange reactions was carried out, considering the composition of Cretaceous marine waters and the possible composition of the continental aquifer at that time (leaching of basaltic rocks).

Finally, we show the importance to have a geochemical model to better understand the depositional environment of magnesium clays and to have plausible parameters to simulate forward models of pre-salt carbonates for example.

Physico-mechanical characteristics of the onyx marble from Sidi Roumane (Northeastern of Algeria)

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The Sidi-Roumane massif belongs to the Felten-Ouled Sellem series of Constantinian massifs, which include Pb-Zn mineralization and onyx marble that were mined in the past. In this work, the petrographic and physico-mechanical characteristics of the onyx of this region will be established in order to define their field of use.
Geologically, the Sidi Romaine massif is composed of neritic limestones of Cenomanian age in monoclinal structure affected by a series of faults of N-S, NW-SE and E-W orientation. The N-S fracture set comprises the bulk of the onyx marble. Petrographically, the onyx presents different textures with irregular laminae more or less horizontal, translucent, white, brown or black with oxidized laminae. Microscopically, they are laminar structures of calcitic crystals columellar, squat, mosaic or in the form of microbreaks of micritic to micro-sparitic aspect.
Chemical analysis by ICP and SAA gave a Ca percentage between 31 and 33.4 %, some samples having a relatively high percentage of Fe, Zn, Al and Mg, given their proximity to the Zinciferous veins. The physio-mechanical properties indicate that the onyx has a density between 2.45 and 2.61 g/cm3 with a total porosity of 3.2 to 9.4%. The uni-axial compression test shows that samples with high porosity have low mechanical strength (10 to 24 Mpa). On these facts, Sidi Roumane onyx can be used as ornamental and decorative stone.

An ancient maritime route in the Adriatic Sea revealed by carbonate petrography and geochemistry

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A large volume of ballast consisting mainly of blocks and pebbles of calcarenites and quartzose calcarenites was recently discovered in the stern area of a sailing vessel that was wrecked in the middle to the third quarter of the 2nd c. BC in Paržine Bay (Ilovik Island, Croatia). The biological assemblages and the siliciclastic content of the rocks suggest a common origin for most of the ballast. The micropaleontological analysis (planktonic foraminifera) as well as the Sr isotope ratios of both benthic and planktonic foraminifera indicate an age more recent than 500 ka. Four main lithofacies have been identified from micro- and macroscopic analyses: 1) tightly cemented bioclastic quartzarenite and quartzose calcarenite with flute-casts (LF1A), 2) cross-bedded, tightly cemented quartzose calcarenite and calcarenite (LF1B), 3) rhodalgal-molluscan floatstone with quartzose calcarenite matrix (LF2), 4) poorly cemented, bioturbated quartzose calcarenite and calcarenite (LF3). Although the LF1B lithofacies may represent aeolianites, which are very ubiquitous on all the coasts of the Mediterranean and Adriatic domain, the other lithofacies are not recognized in Pleistocene and Holocene outcrops on the Croatian coast. A field mission along the Adriatic and Ionian coast of Italy (from Ancona to Taranto) revealed a lithofacies assemblage similar to that of the Ilovik ballast in and near the city of Brindisi (Apulia) within the Middle to Late Pleistocene terraced deposits. The geochemical signatures (C and O) of the ballast matches remarkably with that of the carbonate samples from the Brindisi area. The study of the ballast of the Ilovik-Paržine ship offers direct evidence of a maritime route linking Brindisi (lat. *Brundisium*), one of the major ports of the Apulian coast, to the northern Adriatic in the Late Hellenistic period.

Early Oligocene *Halimeda* bioherms, offshore Palawan (Philippines): an early record of large-scale circulation of the East Asian summer monsoon?

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Pre-Neogene monsoonal archives are rare in south-east Asia and the age of the onset of modern features of large-scale Asian monsoonal circulation is poorly constrained. Neritic carbonates from the proto-South China Sea are used to reconstruct East Asian monsoonal currents and winds during the late Eocene and early Oligocene. Analysis of 3D seismic and well cores from the North-West Palawan block (Philippines) reveals the occurrence of a set of thick (>125 m), aggrading *Halimeda* bioherms, early Oligocene in age. Similarly to Holocene *Halimeda* buildup counterparts, they are interpreted to form in nutrient-rich areas subject to upwelling currents. They possibly reflect the early presence of a strong coastal jet in the Proto-South China Sea, by analogy with the modern summer monsoon. The analysis of the biota in the underlying mixed carbonate–siliciclastic ramp suggests that mesotrophic conditions already prevailed during the late Eocene. Modern-like summer East Asian Monsoon large-scale circulation was therefore possibly active as early as the late Eocene in the Proto-South China Sea. Evidences for upwelling currents vanishes in the late early Oligocene neritic carbonate record which is characterized by the significant development of euphotic hermatypic coral communities reflecting lower nutrient concentrations. Such a biological turnover coincides with the opening of the modern South-China Sea: the southward drift of the North-West Palawan block placed the area away from the Chinese margin and away from the coastal jet.

Pore types, origin and geometry in Aptian Pre-salt deposits from the Santos Basin, Brazil

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The Pre-salt deposits from offshore SE Brazil, correspond to approximately 3/4 of the total hydrocarbon production of the country, and are therefore the subject of various studies aimed at better understanding the primary and diagenetic controls on reservoir quality. The Barra Velha Formation (Aptian, Santos Basin) constitute the main reservoirs of the Pre-salt sag section, essentially composed of calcite spherulites and fascicular aggregates, and magnesian clays, and intraclasts reworked from these phases. The pore systems of these rocks are highly complex, owing to the depositional and diagenetic controls on porosity and permeability, which origin and distribution are difficult to understand. This study aims to understand the origin and geometry of the main pore types of the *in situ* and reworked deposits, integrating X-ray computed microtomography (µCT), which allows to visualize the pore geometry in 3D, with detailed petrographic analysis, performed on 37 samples from a selected well. The samples consist of *in situ* shrubstones, mudstones, shrub-spherulstones, muddy spherulstones, and of reworked intraclastic deposits. The average µCT porosity in the *in situ* rocks is 3.57%, reaching a maximum of 8.57% in samples with complete matrix dissolution. The pore systems of these rocks comprises mainly inter-aggregate pores, and subordinate intra-aggregate and fracture pores. Inter-aggregate pores, formed mainly by matrix dissolution, have elongated morphology and are arranged among the fascicular calcite aggregates. The average µCT porosity in reworked rocks is 5.87%, with a maximum of 18.52%. The pore systems of these rocks comprise mainly interparticle and intraparticle pores, with subordinate vugs and grain-fracture pores. In general, the pore systems of *in situ* rocks differs from those of reworked rocks in terms of pore size and connectivity. Reworked rocks have higher permeability values corroborating the better connection seen in the 3D µCT images. Although µCT analyses provide important information on the pore systems distribution, they cannot discriminate minerals with similar densities, and therefore access the effects of diagenesis on reservoir quality. The integration of petrography with microtomography provided important genetic information on the geometry of the main pore types and on the diagenetic processes that contributed to enhance or decrease the porosity of the reservoirs, helping to understand the origin of their pore systems, and improving the characterization of the distribution of their quality.

Composition of recent coral reef-derived sediments across the remote Chagos Archipelago

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The production of carbonate sediments by coral reef organisms is essential for the formation and maintenance of tropical beaches and is especially important for low-lying islands. Since global coral bleaching events have substantial impacts on reef communities, even in areas characterised by minimal local human impacts, reef islands are highly vulnerable to anthropogenic climate change. Thus, with the ongoing degradation of coral reef ecosystems and sea-level rise, better understanding of reef-derived sediment supply has become increasingly important. We therefore analyse the spatial distribution of the main sediment components across reef zones around six islands in the uninhabited northern atolls of the Chagos Archipelago, central Indian Ocean, and compare them with adjacent beach sediments. At three of these islands, local seabird guano-derived nutrient runoff has been found to enhance the productivity of some reef organisms. As this may influence their contribution to the sediment, we analyse spatial variations in guano-derived nutrient impacts (i.e. sediment organic carbon and nitrogen contents, and $\delta^{15}N$ ratios) and compare sediment composition around islands with high seabird densities to rat-infested islands with few birds. Initial results reveal elevated $\delta^{15}N$ ratios around islands with high seabird densities, with peaks in the island and beach samples and declining values with increasing distance to shore. Quantifying the contribution of carbonate producers to the sediments show a high variability in the abundance of the main components between different atolls. At sites in Salomon Atoll, the sediment across reef zones is mainly formed by coral fragments (around 50–72%), followed by molluscs (≈7–13%) and foraminifera (≈5–11%), and in minor amounts by *Halimeda* segments (0.7–15%), particularly on the outer reef slope (15–25 m depth). Sites in Peros Banhos Atoll are characterised by a slightly higher contribution from *Halimeda* (3.5–21%), while at the Great Chagos Bank these calcifying green algae segments locally represent the main sediment component. When comparing the abundance of these components in reef and beach sediments, beach sediments across all atolls are primarily composed of corals and molluscs fragments, with additional contributions by foraminifera in some lagoon sites. *Halimeda* segments, however, are underrepresented in beach sediments compared to the adjacent reef sediments. Detailed analyses of benthic foraminifera assemblages across the different atolls show a higher contribution to the lagoonal than seaward sediments, and a slight increase in abundance near islands with high seabird densities compared to islands with few birds. Ongoing analyses will further resolve whether seabird nutrient inputs influence the contribution of other carbonate producers to local sediments.

Sediments and facies of modern warm-water carbonate platforms: a global perspective

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Surface sediment samples (n=752) collected on carbonate platforms and in reef systems in the western Atlantic, the central and eastern Indian Ocean, and the south and west Pacific Ocean, as well as the Persian Gulf have been revisited. Grain composition, texture, mineralogy, and geochemistry have been analysed in a quantitative manner. Fragments of coral skeletons, calcareous algae (*Halimeda*, coralline red algae), mollusc shells, and non-skeletal grains (predominantly peloids) are the most abundant constituent grains. Coralgal, grain-supported textures are common at platform margins, whereas mud- and grain-supported textures with molluscs and non-skeletal grains are ubiquitous in platform interiors. Ten facies were discerned based on multivariate statistics including cluster and principle component analyses. There is a statistically significant correlation between the amount of fines ('mud') and water depth, i.e., depositional energy, however, different facies may be found at a wide depth range thereby challenging intuitive and long-standing concepts of sediment distribution. Aragonite and high-magnesium calcite are the most common carbonate phases. Stable isotopes of oxygen and carbon ($\delta^{18}O$, $\delta^{13}C$) of bulk samples exhibit wide ranges and appear to be controlled rather by general location than by depositional environment within carbonate platforms. Western Atlantic platform samples show the highest $\delta^{13}C$ and those from the Persian Gulf and the eastern Indian Ocean the highest $\delta^{18}O$ values. This might be a consequence of the fact that the former usually contain higher amounts of non-skeletal grains and *Halimeda*; the latter values are likely influenced by elevated salinity in surface waters. Coral fragments appear to be more abundant in Indo-Pacific as compared to Atlantic platform sediments. Regarding the so-called 'oolite problem', it seems that non-skeletal grains are found preferentially where carbonate supersaturation is high and skeletal production and sedimentation rate low. These preconditions are fulfilled not only in the classical western Atlantic locations (e.g., Bahamas), but also in some areas of the south Pacific. The 'mud problem' is controversially discussed, but from a global perspective it appears that biogenic, i.e., detrital origins predominate over abiogenic origins.

Modern microbial carbonate features occurring in the Red Sea: A systematic geological investigation

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After dominating the carbonate rock record throughout the Precambrian, microbial carbonates slowly declined with the rise of higher organisms throughout the Neoproterozoic and Phanerozoic. Although outcompeted in terms of calcification rate, microbes are still ubiquitous in sediments, which is evident from the presence of microbially induced carbonate precipitation (MICP) across a multitude of environments in the Red Sea. Despite their presence in the carbonate system of the Red Sea, their occurrence is yet to be systematically documented. This study will describe and compare the products of MICP in the Red Sea and their respective formation environments.

Samples were collected from different environments including but not limited to shallow marine micritized and cemented sediments, recently discovered modern stromatolites and beach rocks. Biological structures were preserved in glutaraldehyde and dehydrated for analysis. All the samples were characterized using thin-section petrography and Scanning electron microscopy (SEM). Mineral compositions of the samples were analysed using X-ray diffraction (XRD) and SEM-EDX.

A multitude of different types of microbes, associated exopolymeric substances (EPS) and nanometre sized mineral precipitates can be discerned Most samples share the same typical cement morphology comprised of an initial micritic cement succeeded by an needled aragonite or bladed calcite rim. However, differences in the extent of these features can be observed and possibly be correlated to different environmental parameters.

The presence and agency of microbes in carbonate platforms and lagoons along the Red Sea coast are poorly recorded compared to other carbonate environments such as the Bahamas or Australia. Modern analogues for near-normal marine carbonate systems in an arid climate are rare, so possible differences and communalities to better documented humid systems are of interest.

Giant carbonate sediment-wave field in a slope to basin-floor setting, Fort Payne Formation (L-M Mississippian) Tennessee

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Over the past two decades, high-resolution bathymetry surveys have revealed abundant, large-scale sediment waves on modern marine slopes worldwide. However, few ancient analogues have been recognized, possibly owing to the seismic-scale outcrops required for their identification. Sediment waves are large-scale bedforms, with wavelengths ranging from 100s of meters to several kilometres, and amplitudes between a few to 10s of meters. Here we document a giant carbonate sediment-wave field in the Fort Payne Formation (Lower-Middle Mississippian) of Tennessee, eastern United States. The Fort Payne Formation is a distally steepened ramp, which consists of topset-foreset clinothems, up to 90 m thick in Kentucky, and a basinward (south), thinner (15-50 m) bottomset accumulation in Tennessee. Clinothems downlap a condensed section just above the Devonian Chattanooga Shale, which serves as a regional stratigraphic marker. Impressive roadcuts and continuous cliff exposures above streams and lakes provide excellent outcrops for analysis of large-scale stratigraphic patterns. A prolific heterozoan carbonate factory, fuelled by regional coastal upwelling, produced vast amounts of crinoids and lesser amounts of bryozoans and brachiopods. Sediment waves are present in the (1) lower to upper foresets of clinothems, and (2) in the basin-floor bottomsets, which occupy an area in excess of 10,000 km^2. Clinothem sediment waves are ~50-200 m in wavelength, and ~10-20 m in amplitude. Proximal clinothem sediment waves consist of shaley crinoidal asymmetrical bedforms with leeside-thickening rudstone wedges composed of upslope-migrating backset beds separated by scours, interpreted as hydraulic-jump deposits. Distal clinothem sediment waves are symmetrical to slightly asymmetrical, with troughs partially filled by clean crinoidal-rich rudstones up to several meters thick. These represent large, upslope-migrating crescentic bedforms formed from high-density turbidity currents. Basin floor sediment waves are symmetrical to asymmetrical downslope and are generally larger than clinothem sediment waves. Stratigraphic correlations indicate they may have formed in water depths of 100 m or more, with wave lengths >600 m and amplitudes up to 50 m. Some sediment waves are shaley in the lower part and overlain by medium-thick-bedded wackestones. Troughs occasionally consist of wavy-bedded rudstones with thin shale breaks. Impressive backset beds of crinoidal rudstones are documented on the leeside of one large sediment wave, indicating high-density turbidity currents. Abundant crinoid pluricolumnals, some oriented parallel to paleoflow, attest to *in-situ* heterozoan carbonate sediment production across sediment waves. The Fort Payne Formation exposes seismic-scale sediment waves across a slope to basin-floor setting. This research aims to provide a better understanding of hydrodynamic bedforms in a carbonate slope setting from a physical sedimentological approach.

Carbonate precipitation and its relation to weathering of mafic rocks, Pali Aike Volcanic Field, Chilean Patagonia

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Chemical weathering of silicates has an essential effect on moderating the global carbon cycle and Earth's climate, and accounts for approximately 50– 75% of CO_2 consumed on the continents. In natural basaltic systems, chemical weathering of silicate minerals may promote to carbonate mineral precipitation under atmospheric conditions, when the released cations come into contact with natural waters. Cations, such as Ca^{2+}, Mg^{2+} and Fe^{2+} are required for this process. These cations are present mainly in mafic minerals which are abundant in basalt. The Pali Aike Volcanic Field is a basaltic field in southernmost South America where Pleistocene alkaline basaltic lavas crop out. The magmatism source is associated with sub-slab asthenosphere flow through slab windows. The Laguna Timone is a maar that represents a brine developed after explosive volcanic eruptions in a periglacial environment in this area. The lake constitutes an endorheic hydrological system where processes leading to carbonate precipitation (calcite and magnesium calcite) by enrichment of Ca ions originated from weathering of the surrounding mafic rocks. The X- ray fluorescence results showed that PAVF basalt samples contain several elements such as CaO (9.73 - 10.57 wt.%) and MgO (9.49-12.76 wt.%) that can react with CO_2 to form carbonated minerals. X-ray diffraction and petrographic results verify that basalt contains minerals groups of pyroxene (Na, Ca) (Mg, Fe, Al) (Al, $Si)_2O_6$, olivine $(Fe, Mg)_2SiO_4$ and plagioclase feldspar $NaAlSi_3O_8$-$CaAl_2Si_2O_8$ which are suitable for the mineral carbonation process. DIC isotopic signature ($\delta\ ^{13}C$) of water show a variation between stagnant waters (lake) and flowing waters (river). The $\delta^{13}C$ DIC values of the lake are approximately between −12‰ to −16‰ and river has values of -7‰. These values are associated to three possible sources: weathering of the silicate by carbonic acid, atmospheric CO_2 and degradation of organic matter. Sr isotope ratios data of carbonates (tufa fragments and carbonate crust) has a range (0.70408-0.70475) between values of Pali Aike volcanics basalts and Patagonian top soils. These values are indicative of its derivation primarily from the weathering of Pali Aike basalts (0.70316 to 0.70351) including exogenous input more enriched in ^{87}Sr associated to strong winds and Sr leaching from topsoils (0.705382). In addition, a carbonate vein located in tuff ring wall of crater has Sr isotope ratios (0.70265 to 0.70314) in the same range of the Pali Aike Mantle Xenoliths (0.70264 to 0.70431). These data indicated that primary sources of carbonate precipitation are related with the parent geologic material, in-situ weathering mafic and ultramafic volcanic rock.

Cold-seep carbonates as geological archives: from molecular fossils to glacial tectonics

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Active as well as passive continental margins host numerous areas where methane emits from the sediment into the ocean at methane seeps. The key process at marine methane seeps is the anaerobic oxidation of methane (AOM) mediated by a microbial consortium of methane-oxidizing archaea and sulphate-reducing bacteria. A consequence of microbial-mediated AOM is the precipitation of authigenic cold-seep carbonates. Cold-seep carbonates occur in various sizes and forms, for example cm-sized early diagenetic concretions, meter-sized seafloor carbonate pavements, and decametre-sized carbonate buildups. Cold-seep carbonates are geological manifestations of microbial activity and biogeochemical element cycling at methane seeps. Here I will present results of three case studies including one Carboniferous and two modern cold-seep carbonate deposits, demonstrating the exceptional potential of cold-seep carbonates as geological archives preserving molecular fossils and glacial-tectonic movements.

Preservation of orbital forcing in incomplete carbonate successions

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Cyclostratigraphy has the potential to establish relative ages in sedimentary records with a temporal resolution greater than that of absolute dating methods such as radiometric dating. Though, stratigraphic incompleteness complicates this process and is a source for uncertainty in cyclostratigraphic age-depth models. As a result, cyclostratigraphic studies on sedimentary archives from pelagic and hemi-pelagic environments are usually less contested than those on more shallow-water sections.

To better quantify the impact of stratigraphic incompleteness on cyclostratigraphic results, we first quantify stratigraphic completeness throughout a carbonate platform, and then assess the impact on the recorded Milanković signal.

Two-dimensional dip-sections generated by CarboCAT models of carbonate platform growth forced with insulation-driven eustatic sea-level oscillations generate synthetic stratigraphic columns and proxy records, and these are analysed for presence of an insolation signal using the astrochron package.

Our results show that if sea-level is driven by a Milanković signal, shallow-water carbonate successions with moderate incompleteness are capable of recording said signal. This suggests that under accommodation-forcing by a Milanković signal, cyclostratigraphy can help establish relative time scales in shallow-water environments.

Development of a high relief isolated carbonate platform in the Pre-Salt Aptian Barra Velha Formation, Santos Basin, Brazil

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The Aptian Barra Velha Formation of the Santos Basin offshore Brazil is a natural subsurface laboratory for the study of thick and laterally extensive lacustrine carbonate sedimentation. In this basin there has been intense debate concerning the potential development of carbonate depositional environments in hyper alkaline lake waters. One school of thought is that the lake was predominantly shallow and there was little or no relief. In contrast, others describe a range of carbonate platform, slope and basin morphologies from seismic. Here, through the integration of seismic, sedimentological, geochemical and structural data we present the key seismic facies, depositional facies and developmental stages of a lacustrine carbonate platform founded onto a complex paleotopography of faulted basaltic tectonic highs and accretionary volcanic pedestals. Integration of the data points to the development of an isolated carbonate platform with distinctive platform interior, margin and high angle/relief slopes. Carbonate platform development reflects the interplay between lacustrine sedimentation, tectonics, volcanism and lake level changes. As such, the study results make an important new contribution to the understanding lacustrine carbonate platform, slope and basin development.
Most published data concerning the Barra Velha carbonates has been biased towards structures positioned close to the crest of a long-lived tectonic high; the São-Paulo plateau (i.e. Lula and Sapinhoá) where accommodation space was limited. However, quite different Barra Velha lacustrine carbonate systems occur off the crest of the São-Paulo high, and are characterized by elongate tectonically-controlled isolated carbonate ridge-mounds. In seismic data these show evidence of several hundred metres of depositional relief. The study area is located c. 90 km northwest and downflank of the São-Paulo high. It is covered by a high quality 3D seismic dataset and penetrated by 5 wells. Seven distinct stages that control carbonate platform, slope and basin development are differentiated; 1) initiation of Barra Velha deposition, 2) subaerial exposure and deposition of >500 m of Parati basin-centre flood basalts, 3) extensional faulting of the Parati volcanics, 4) transgression and re-establishment of Barra Velha carbonates, 5) renewed sub-lacustrine to subaerial volcanism that contaminated and locally overwhelmed Barra Velha carbonate sedimentation (Picinguaba magmatic event), 6) the cessation of volcanism, lake level fall and reworking of the volcanics, 7) progressive transgression and the re-establishment of Barra Velha mixed carbonate-clastic and carbonate deposition (BVE200-100). As the lake level rose the carbonates built ridge mounds and margin mounds that enclose a platform interior and delimit high relief slope systems.

Reservoir Description and Rock Typing in Heterogeneous Brazilian Pre-salt Carbonate Reservoirs

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The Brazilian Pre-salt carbonate reservoirs are known for their complex and heterogeneous nature, making it challenging to accurately ascertain the arrangement of petrophysical characteristics. The diversity and variability in the porous system structure of these reservoirs pose a significant obstacle in clearly classifying rock types and characterizing the reservoir using conventional approaches. Hence, it is crucial to have a comprehensive understanding of the correct cluster number and rock type classification based on petrophysical properties. In this work, the 774 plug porosity-permeability data from two wells of Santos Basin were analysed. The K-mean unsupervised learning algorithm was utilized to divide the data into four reservoir rock types based on their petrophysical parameters. Plug data and corresponding well logs data including Density, Gamma-ray, Neutron, Photoelectric factor, NMR, Electric resistivity logs, and porosity profile created from image log were used as inputs for the algorithm to ensure that the data within each cluster had similar characteristics. According to the input data, the technique located the centre of each cluster and divided the data points into matching groups. The elbow curve approach was implemented to choose the optimal cluster size. To do this, the clustering problem for the input data set was solved for different k values. For each choice of k, the Sum of Squared Error (SSE) between data points in a cluster and the cluster centroid was determined. The SSE was then plotted versus each value of k. The elbow on the line graph, which resembled an arm, presented the best k value, which was found to be four in this investigation. The results of the reservoir rock type classification were examined to evaluate the quality and geological characteristics of the studied sequence. The results of the reservoir rock type classification provided insights into the quality and geological characteristics of the studied sequence. The approach used in this study can help in accurately identifying rock types and characterizing reservoirs with heterogeneous petrophysical characteristics, which could aid in better reservoir management and production optimization.

Using forward modelling to test hypotheses on the preservation of time in marine carbonate records

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Multiple applications, including palaeoenvironmental reconstruction and phylogenetic inference, expect geological data to come with a handy set of ages. Substantial effort is put into developing tools to infer age-depth models that quantify the uncertainties of age tie-points and account for error propagation of these uncertainties. It is striking how commonly these approaches disregard sedimentological models of how time is preserved in rocks. Or is it because the models are contradictory? Carbonates, in theory, should be highly resolved time archives: their mineralogical and skeletal composition is the product of fine-scale changes in the environment, including the climate, and they are – in many cases – authigenic and autochthonous. Nonetheless, radically different concepts of how time is recorded in carbonates coexist in the sedimentological community, not only in terms of *how much* and *what parts* of the time is recorded but also *where* in space. Existing paradigms alternatively attribute this spatiotemporal distribution to Milankovitch forcing, autogenic processes such as biological or diagenetic self-organization, or stochastic variation, in each case assuming either a facies belt or mosaic distribution of facies. Rarely are these alternatives subject to systematic testing and, when tested, they are often assumed to be mutually exclusive.

Forward models allow systematic testing of hypotheses on the preservation of time in strata under different driving mechanisms and on the distinguishability of these mechanisms. Making these hypotheses testable using empirical data remains largely an open challenge that relies on collaboration. Even though the identification of underlying processes and their parameters is certain to be non-unique, it can be handled by probabilistic methods to represent uncertainty. Allowing for multiple mechanisms driving deposition, operating in concert at different spatial and temporal scales, is necessary to integrate carbonate sedimentological processes into age-depth modelling and it has the potential to improve them substantially.

Reactive-transport model of calcareous rhythmites: can they form through self-organization?

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Calcareous rhythmites, also known as limestone-marl alternations, are widely used as high-resolution archive of periodic climate changes. In many cases these climatic changes can be correlated with astronomical forcing of insolation reaching the Earth's surface, which results in rhythmic changes in the rates of weathering and carbonate production. However, the formation of the rhythmical lithification pattern is in many cases related to calcium carbonate dissolution and precipitation during early burial, controlled by the aragonite content of the sediment. This is important, because aragonite is a metastable phase and can, together with the stable mineral phase calcite, form a non-equilibrium dynamic chemical system. Many such (geo)chemical systems can form cyclic patterns without external forcing and such pattern formation has been widely reproduced experimentally and through modelling. In the case of aragonite-calcite sediment mixture, a one-dimensional reactive-transport model has been proposed by L'Heureux (2018) and it includes a geomechanically component of sediment compression leading to changes in porosity, which is necessary for an oscillatory behaviour to appear. Such reactive-transport models are extremely numerically challenging. Here we present our attempts to reproduce this model and to identify parameters leading to diagenetic formation of cyclic patterns in calcite concentration that would be preserved in the sediment column as limestone beds. Reactive-transport models hold a great promise in understanding carbonate diagenesis, but our case highlights the need for reproducible modelling practices in the sedimentological and geochemical communities. We also highlight that the spatial and temporal distribution of early aragonite dissolution in sediments remains very poorly understood and appears to have shifted between deep-time and modern environments.

Ecological transitions and their effects on reef islands: Holocene and modern insights from Indonesia

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Reef islands are flat accumulations of soft carbonate sediments that formed since the mid-Holocene in the proximity of reef ecosystems through the interplay of biological sediment production and wave-driven transport processes. Not only rising sea level, but also alterations in sediment-producing reef ecosystems, make the future development of reef islands a matter of scientific debate. To enhance the understanding of reef island dynamics, sedimentological studies may be used to assess geological effects of, e.g., sea-level fluctuations and ecological transitions on these societally important landforms. Our study presents an evolutionary model of Holocene reef island formation and modern island dynamics in Indonesia, Southeast Asia. We use a total of 53 sediment samples, retrieved from deep push cores and shallow boreholes on a densely populated island, analyse their grain size distribution and skeletal composition to describe the facies, and use radiocarbon dating to construct a geochronological framework. Complementing shoreline analysis using satellite imagery reveals the island dynamics of the past 24 years. Our results suggest that the initial soft sediments, which are almost exclusively composed of coral fragments, were deposited during a sea-level high-stand ~5,800 years BP. We link this limited skeletal grain spectrum to vertical reef growth, probably catching up with the high-stand. The initial sediments are overlain by more diverse coral-dominated sediments with increased distributions of gastropods, calcifying algae, and foraminifers. These sediments were deposited soon after the sea-level had reached its contemporary height around 4,200 years BP, likely indicating that the sea-level fall induced an ecological transition. The youngest sediments close to the recent shoreline contain high proportions of the calcifying green algae *Halimeda*, suggesting that the supplying reef ecosystem has lately transitioned towards increased macroalgae growth. Importantly, the shoreline analysis provides evidence of predominant accretion resulting in the expansion of surface area by 13% between 1999 and 2023, suggesting that the ecosystem shift has not destabilized the island. In the context of increasing reports of coral reef disturbance and the subsequent establishment of macroalgae in these, our findings are of global importance for the interpretation of future carbonate sediment budgets and dynamic carbonate sediment systems.

The influence of climate cycles on hydrology, chemistry, and sedimentation in alkaline lakes: insights from process-based modelling

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Alkaline lakes are important carbonate and silicate mineral factories that can sequester CO_2, form hydrocarbon reservoirs, and record palaeoclimate evidence. These lakes are highly-sensitive to changes in climate (hydrology) and catchment lithology. Hydrogeochemical modelling can help us to understand past climates and the conditions under which different lacustrine minerals may form.

We present a geochemical model of alkaline lake water chemistry and sediment evolution (through kinetics-controlled water-mineral reactions in PhreeqPy) sequentially iterated with a process-based catchment water-balance model, evaluated by application to the South Atlantic Pre-salt, cyclic carbonate, clay, and silica deposits.

The chemistry of riverine/groundwater influx is controlled by composition and relative abundance of igneous rock (plutonic and volcanic) and limestone in the catchment. With constant inflow chemistry, changes in lake water chemistry are driven by cyclic variations in evaporation-rainfall over the lake and inflow from the catchment. The resulting vertical changes in thickness and abundance of calcite, dolomite, and Mg-clays reflect the kinetic rates of mineral-water reactions relative to timescales of changes in the hydrological cycle and the elevation of any spill-point. If the rate of climatic change is on the same order as the mineral-water reactions, lake waters maintain near-equilibrium with their sediments. More rapid climatic change outpaces mineral-water reactions, moving the water out of equilibrium and altering the proportions of precipitated mineralogies.

Critically, predictions differ radically from those of simple thermodynamic models that ignore coupling with catchment hydrology. This work provides a basis on which to incorporate early diagenesis of the primary minerals, that might further improve correlation with the observed sequences.

Carbon isotope record of Paleocene-Eocene hyperthermal event in a shallow carbonate ramp succession, Adriatic Carbonate Platform, Slovenia

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The Paleocene-Eocene Thermal Maximum (PETM) represents one of the most extreme global warming events in the Cenozoic, characterised by an abrupt and short-lived temperature increase of 5-8°C. The PETM was associated with a pronounced negative carbon isotope excursion (CIE) recorded globally in different depositional settings from palaeosols to deep-sea sediments. The CIE is related to a geologically instantaneous (5-10 ky) massive release of ^{13}C-depleted C to the ocean-atmosphere system at the PETM onset. Because of its global occurrence and a relatively short duration (~100-200 ky), the CIE has been selected as a criterion defining the Paleocene-Eocene (P/E) boundary. Several recently documented P/E sections have also captured a transient precursor event, termed the pre-onset excursion (POE), indicating multiple C injections associated with the PETM onset. This study presents facies analysis and the C and O stable isotope signatures of a fully recovered core (T1-7) from the northern part of the Adriatic Carbonate Platform in SW Slovenia. The area provides an outstanding example of a long-term shallow-marine carbonate platform system, spanning from the lower Paleocene to the middle Eocene, composed of an aggradational ramp sequence. The P/E boundary interval in the core is characterised by a 15 m thick succession of alternating, m-thick layers of unsorted and burrowed *Alveolina*- and larger miliolid-dominated wackestone/packstone and miliolid, rotaliid and echinoderm-rich packstone facies without discontinuities. All facies assemblages correspond to an inner ramp, most probably a seagrass-related euphotic depositional environment. Stable isotope analysis of bulk and matrix carbonate sampled along a 50 m long core section has revealed a clear negative δ^{13}C isotope excursion (2-2.5‰), corresponding to a distinctive, ~5 m thick bioturbated bioclastic unit with rare larger benthic foraminifera (LBF). The pattern and magnitude of the main CIE recorded in the T1-7 core is in accordance with the published data for bulk carbonate and benthic foraminiferal δ^{13}C excursions in the PETM interval. Furthermore, higher resolution sampling of the core has also revealed a discrete, lower-magnitude negative excursion (1-1.5‰), which might correspond to the POE recorded in a few PETM sections worldwide. However, the reliability of the carbon isotope record of the T1-7 core, based on bulk rock samples, is hampered by a heterogeneous isotopic signal of the benthic carbonate material, which is not necessarily indicative of the global carbon signature, and particularly by a presumably thick taphonomically active (bioturbated) zone in the shallow ramp environment, resulting in strong mixing of the sediment and averaging of the isotopic signal. This study in progress has focused on re-evaluation of the carbon isotope record by comparative analysis of single components (LBFs, matrix) and the bulk sediment along the PETM interval.

The impact of synextensional hydrothermal processes into Cretaceous synrift carbonates (eastern Basque-Cantabrian Basin)

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A good knowledge on the diagenetic evolution of tectonically active areas is crucial when syntectonic fluid migration is involved. Inverted hyperextended basins such as the western Pyrenean Basque-Cantabrian Basin (BCB), can provide new insights in understanding the interaction between multiscale extensional tectonics and diagenetic processes. Such diagenetic and extensional processes are well registered in the Cretaceous rocks of the Central Depression, that is, the southern margin of the Palaeozoic Bortziriak-Cinco villas massif. Based on an exhaustive petrographic study combining optical microscopy and cathodoluminescence observations, together with $\delta^{13}C$ and $\delta^{18}O$ stable isotope data from limestones end diagenetic carbonates, synextensional hydrothermal processes have been identified in middle to Upper Cretaceous rocks. Mineral paragenesis, cement stratigraphy and the presence of resedimented diagenetic limestone fragments embedded into younger deposits, evidence an early hydrothermal transformation of marine sediments. This hydrothermal alteration is distributed in time into the following three phases: 1) a widespread and intense aggrading calcite recrystallisation or neomorphism (Cal1) followed by partial silicification (Qtz1) and albitisation (Ab1) processes; 2) calcite veining (Cal2) and coetaneous dolomitization (Dol1) and pyritization (Py1) of limestones and younger terrigenous sediments; 3) localised calcite neomorphism (Cal3) associated to the precipitation of saddle dolomite (Dol2) and spastic calcite (Cal4). Carbonate mineral isotopic data show an enrichment relative to the lighter stable isotopes. Relatively low $\delta^{13}C$ and $\delta^{18}O$ stable isotope values suggest an increase in the geothermal gradient and a possible interaction of deeper fluids, respectively. Textures and mineralogical paragenesis also suggest changes in the composition of the fluids through time, which could mean a provenance variation of the fluid and/or different fluid-rock processes. All these evidences are in accordance with the geodynamic setting for the middle and Late Cretaceous, when deep-rooted faults and salt tectonics were very active. The early emplacement of authigenic minerals into synrift deposits, could reflect the development of hydrothermal systems caused by the increase of the geothermal gradient associated to the intense extensional tectonics that were ongoing in the hyperextended BCB during the middle to Late Cretaceous.

Early Aptian discontinuities developed in Constantine Platform: morphology, diagenesis feature and palaeoenvironmental interpretation

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Aptian-Albian facies of Constantine region are represented by transgressive-regressive successions of marine carbonate deposited principally in shallow marine platform. Sedimentary discontinuities that mark the Late Early Aptian are often indicated as distinctive surfaces in outcrop intervals. Field appearance in thin-section and cement structure of micro-sample carbonates led to distinguish two type of discontinuity. In the north of the platform, an exposure surface is observed in supratidal facies with mud crucks structures, speleothems structures and non-ferroan meniscus cements formed in the vadose zone that indicate an exposure surface. In the south of the platform, a hardground shows marine fibrous cements and non-ferroan dogtooth cements developed especially in shoal facies and characterise the marine phreatic zone.
This composite discontinuity, primarily formed in a margin environment, was afterward exposed to meteoric conditions, as proved by ferroan stalactite cements. This major erosion surface marks the top of the Early Aptian appears to be relatively synchronous on the studied sections. The origin of this surface is linked principally to the tectonic reorganization of the Constantine platform initiated in the Lower Cretaceous.

The influence of depositional and eodiagenetic processes on the hydrocarbon generation potential of Aptian Pre-salt deposits in the Santos Basin, Brazil

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The Pre-Salt reservoirs, especially the Barra Velha Formation (BVF) of Santos Basin, are responsible for more than 70 % of Brazil daily hydrocarbon production. Besides the important reservoirs, these deposits also contain intervals that constitute potential source rocks of local importance in the basin. The BVF comprises *in situ* rocks, composed mainly of Mg-clay matrix, spherulitic and fascicular calcite aggregates, and redeposited rocks, composed of intraclasts reworked from these aggregates. The objective of this study is to understand the impact of depositional and eodiagenetic processes on the hydrocarbons (HC) generation potential of the BVF. For this, 52 core samples were analysed through quantitative petrography and Rock-Eval pyrolysis. The *in situ* rocks show an overall higher HC generation potential (avg. 3.26 mg HC/g rock; fair) than the redeposited rocks (avg. 0.37 mg HC/g rock; poor), related to the redeposition process that promoted the winnowing of the clay matrix and favoured the degradation of organic matter. The samples exhibit a positive correlation between the proportions of laminated Mg-clay matrix and the HC generation potential, implying that the organic matter occurs associated with the matrix. Considering this, the eodiagenetic processes that reduced the HC generation potential involved the dissolution, displacement, and replacement of the original matrix. The *in situ* interval with the lowest HC generation potential (avg. 0.51 mg HC/g rock, poor) also has the lowest volumes of preserved matrix (avg. 3.3 %), due to dissolution and shrinkage processes that generated porosity (avg. 4.2 %), and the replacement of matrix by fascicular calcite aggregates (avg. 47.0 %). The interval with the highest HC generation potential (avg. 4.80 mg HC/g rock, good), also has the highest amount of preserved laminated clay matrix (avg. 20.0 %). In this interval, the major matrix-replacing phase is calcite spherulites (avg. 38.6 %), being the main cause for the reduction of the HC generation potential in some samples. Thus, redeposition and eodiagenetic processes can influence negatively the HC generation potential of BVF rocks, reducing from average good, in *in situ* rocks with preserved matrix, to poor, in redeposited rocks or *in situ* rocks with diminished amounts of matrix due to eodiagenetic processes.

Calcite U-Pb geochronology applied to diagenetic history of karstified and microporous carbonates: the Urgonian Karstic system of Monts de Vaucluse, SE France

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The prediction of carbonate rocks properties, hosting potential karst aquifers, represents a major scientific challenge for sustainability of water resources at local and global scales. The spatial distribution of the reservoir properties controls the aquifer parameters and the flow behaviour but are not simply related to the present day thermodynamic and hydrological conditions. They are the result of the complex geological history (early /late diagenesis, faulting, fracturing…) from deposition to the formation of the present day aquifer and active karstic system. Understanding this long-lasting and complex evolution of the carbonate reservoir properties is critical for predicting its present-day flow dynamics. To address this issue, we must be able to reconstruct the complete genesis of the karst system and to understand the inheritance of the earliest diagenetic phases and paleo-karstic events on the resulting today karstic reservoir properties and behaviour.

The Albion R&D project is dedicated to the understanding and modelling of fluid dynamics at various scales of the Urgonian Formation formed by outcropping rudist-rich limestones of Barremian-Aptian ages that constitute both an outstanding groundwater reservoir (Fontaine-de-Vaucluse karst aquifer) and an analogue of Middle-East oil and gas microporous reservoirs.

In this context, we use U-Pb geochronology all the sur-imposed calcite diagenetic phases to reconstruct the multiphase diagenetic events controlling the reservoir heterogeneities.

We combine LA-ICPMS U-Pb dating, classical C and O isotope measurements and associated petrographical/cathodoluminescence analyses on exceptional vertical and horizontal core data for the LSBB gallery (Rustrel, Monts de Vaucluses) and additional samples from outcrops and Albion database. 24 ages for calcite cements have been obtained with an accuracy < 1Ma to document the diagenetic history of this Urgonian Karstic reservoir: 1) a first major diagenetic event from 95 to 89 Ma, following the deposition of rudist-rich carbonate platform <125 Ma and corresponding to the shallow burial meteoric development of microporosity and blocky cements in the intergranular pore space, linked to the so-called « Durancian phase »; 2) two distinct phases at 40-36 Ma and 27 Ma, of fracturation and cementation under meteoric derived burial fluids; 3) two/three main episodes of karstification at 13-10 Ma; 4) one episode of karstification at 9-8 Ma, filled by micritic sediment/ quartzose sediments and 5) one last episode of karstification at 3-1 Ma, materialized by speleothems.

By identifying the precise chronology and origin of these diagenetic phases and by conceptualizing the processes of paleo-fluid flow linked to tectonic events, we aim to better constrain compartmentalization and fluid flow modelling of the karstic reservoir.

Characteristics and Formation Mechanism of the Carbonate Reservoirs in Sinian Dengying Formation in Sichuan Basin, China

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In recent years, significant breakthroughs have been made in the exploration of deep marine carbonate rocks, becoming an important field for future oil and gas exploration and discovery in China. Taking the Dengying Formation in the Penglai Gas Field of Sichuan Basin as an example, the genetic mechanism of high-quality deep to ultra-deep marine carbonate reservoirs is systematically analysed through various data such as core, logging, seismic analysis, and testing. The main types of rock include laminite, stromatolite, spongiostromata-type dolostone, thrombolite, cyanobacteria bound frame dolostone, cyanobacteria related dolarenite, cyanobacteria related carbonate breccia, etc. and the frame-like structure is an important sedimentary structure in the microbial mound. The Dengying Formation in Sichuan Basin is carbonate platform facies. The microbial mound-shoal complex is the widespread facies. Microbial mound-shoal complex can divide into five parts as mound base, mound core, mound flat, mound cap, mound flank. Dolomitization and dissolution are important diagenesis of the reservoir. The framework residual pores are the principal reservoir space.

The results indicate that the dolomite reservoir of the Dengying Formation in the Penglai gas area is mainly composed of secondary dissolution pores and caves, and the reservoir has the characteristics of vertical stacking and horizontal continuity. The deposition of mound beach complex is the dominant facies type of the reservoir. The Dengying Formation reservoir has gone through five stages in sequence, including syngenetic quasi syngenetic stage, shallow burial stage, epigenetic stage, burial stage, and deep burial adjustment. Research suggests that the control of sedimentary facies is the material basis for the development of deep to ultra-deep carbonate reservoirs. The characteristics of rock fabric affect the development and evolution of reservoir pores, and further adjustment of multiphase diagenetic fluids improves the physical characteristics of deep reservoirs. The reservoir has strong heterogeneity characteristics, and high-quality reservoirs have the characteristics of multi factor joint control and multi-stage composite genesis. The effective identification of advantageous sedimentary facies zones and reservoirs is the key to predicting deep to ultra-deep carbonate reservoirs and characterizing traps.

Depositional environments and microbial origins of Middle Ordovician ferruginous ooids in the Upper Yangtze region, South China

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Middle Ordovician ferruginous ooids in the Upper Yangtze region of South China are composed mainly of hematite and/or chamosite and occur in mixed siliciclastic and carbonate successions ranging from the Darriwilian to potentially the lower Sandbian. This mineralogical differentiation has a distinct paleogeographic pattern, with hematitic ooids distributed in the western part and chamositic ooids largely in the eastern part of the study area. Comprehensive studies of three ferruginous ooids-bearing Middle–Upper Ordovician successions, including Songliang section with hematitic ooids, Renshi-1 core and Yanping section with chamositic ooids, recognized 19 microfacies, which can be grouped into eight associations: iron grain with abundant well-sorted quartz (IA), iron grain with abundant hardgrounds and microbial structures (IB), ooid-cortoid-peloid and green algae (OG), peloid and bioclast (PB), peloid dominance (PD), non-specific bioclast (B), siliciclastic and carbonate mud (M) and Quartz (Q) microfacies associations. The results reveal that hematitic ooids co-occur with well-sorted and well-rounded quartz and formed in the shoal setting, when the depositional environments changed from restricted lagoon to bioclast–quartz shoal and open-marine subtidal. In contrast, chamositic ooids formed in a semi-restricted lagoonal environment, favouring active microbial coating of the ooids under low sedimentary rates during rapid sea-level rise. Iron content is only moderately positively correlated with terrestrial materials as revealed by logging data of Renshi-1 core, indicating iron enrichment herein is probably decoupled with enhanced terrestrial supply. Microbial activities may have played a major role in concentrating dissolved iron in the ooids, as indicated by close association of iron deposits with porous layers with amorphous carbon within ooid cortices, as well as abundant coeval microbial structures and, notably, stromatolite-like iron ‘cauliflower’ structures. The hematitic ooids suggest a nearshore agitated-water depositional environments, corroborated by theirs paleogeographic separation from chamositic ooids.

Dolomite Stoichiometry as a Tool for Testing Dolomitization Models

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Dolomite stoichiometry is a commonly reported metric in many dolomite studies; however, its utility has yet to be fully explored. High-temperature dolomite synthesis experiments have demonstrated that various physical and chemical conditions strongly control dolomite stoichiometry (e.g., fluid Mg:Ca, temperature, salinity, precursor mineralogy). Further, field observations suggest that temporal and spatial variations in dolomite stoichiometry may accurately record environmental changes that could be used to infer the spatial and temporal evolution of the dolomitizing fluid. Based on these observations, we propose that dolomite stoichiometry can be applied as a proxy for changes in the composition of the dolomitizing fluids as a result of (i) changing paleoenvironmental conditions through time or (ii) evolving fluid chemistry along a hydrological flow path (e.g., decreasing Mg:Ca as dolomitization occurs). Here, we present evidence based on results from three case studies, illustrating trends in dolomite stoichiometry that elucidate the mechanism and conditions of dolomitization. These case studies include (1) the Early Cretaceous Upper Glen Rose (UGR) Formation in Central Texas, (2) the Eocene Uteland Butte Member (UBM) of the Green River Formation in Central Utah, and (3) Mio-Pliocene Seroe Domi (SD) Formation located at Seru Grandi on the Island of Bonaire.

In the first example, the UGR, peri-tidal depositional cycles consisting of facies reflecting deepening and shallowing correspond to patterns in dolomite abundance, stoichiometry, and $\delta^{18}O$. Coupled with petrographic evidence, these observations suggest early dolomitization that recorded local variability in fluid chemistry driven by changes in water depth. In the second instance, the UBM consists of lacustrine carbonate depositional cycles defined by facies patterns that oscillate between deepening and shallowing, corresponding to trends in dolomite abundance and stoichiometry. Spatial and temporal relationships between facies and dolomite stoichiometry suggest early dolomitization and that the observed trends were driven by differences in fluid chemistry associated with lake-level fluctuations through time. In the final case of the study, the SD consists of four bioclastic progradational units, each characterized by a unique distribution of stoichiometry values that increase over time as the platform progrades. These trends suggest that early dolomitization occurred whereby each progradational unit was dolomitized by a unique fluid chemistry. Presumably, these fluids evolved synchronously with changes in the platform geometry. Collectively, these studies illustrate the value of dolomite stoichiometry as a proxy resource, though the degree of later alteration due to recrystallization must be evaluated. Since dolomite stoichiometry has been shown to reflect local diagenetic conditions but can be overprinted by progressive recrystallization.

Hypogenic void systems in Mississippian carbonates (UK) and implications for geothermal heat production

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Hypogenic void-conduit systems may comprise both non-stratabound and stratabound components that display morphological features of rising flow. They are formed by upward-flowing fluids, with dissolution attributable to fluid cooling, fluid mixing, changes in redox and/or pH due to injection of CO_2 or H_2S-rich water and pressure. Despite an increasing number of studies of hypogenic void-conduit systems, they are still less well characterised than epigenic systems that are formed by direct surface recharge.

Non-stratabound cavities of possible hypogenic origin intercepted by epigenic caves and mines, and sometimes exhumed within outcrops, have been recognised in Mississippian carbonates on the Derbyshire Platform, Northern England (UK). These carbonates are potential geothermal targets for low-medium enthalpy heat. Such cavities include: 1) open vertical and sub-vertical cavities; 2) partly to completely mineralised cavities with hydrothermal minerals; and 3) calcite-lined and calcite-filled cavities. Calcite in the latter is often very coarsely crystalline, with well-formed crystals commonly >5 cm diameter, that represent the last cementation event. Some of these cavities may contain a later sediment fill.

This study assesses relationships between hypogene cavity occurrence, fill, morphology, size, location and geological context and the timing of hypogene development, including association with faults, stratal architecture, and diagenetic phases. It combines geological and geochemical analysis, which will be used as constraints for numerical models that aim to better understand the genesis and evolution of hypogene cavities and assess their potential role as fluid pathways. Thin sections of coarsely crystalline calcite examined under CL microscopy, show no to dull luminescence. Preliminary analysis of isotope composition of coarsely crystalline calcite samples shows low $\delta^{18}O$, probably reflecting precipitation at high temperature or from isotopically depleted groundwater. Although the majority of $\delta^{13}C$ is generally positive, there are some negative values that might suggest groundwater depletion and/or magmatic CO_2.

Reactive transport modelling (RTM) of hypogene dissolution is used to predict the spatial distribution and nature of resulting hypogenic void-conduit systems. RTMs enable rigorous and systematic evaluation of the effects of fluid temperature, mixing redox and pH changes due to addition of CO_2 and/or H_2S and to build and test conceptual models.

Unlocking the reservoir quality complexity in resedimented carbonate: an example from the Zechstein Mid-North Sea High

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Permian Zechstein carbonates offshore UK are back on the "frontier play exploration spotlight" after the recent discovery of the Shell-operated Pensacola well. The well is located along the southern margin of the Mid North Sea High and is quoted to be one of the largest gas discovery in the region in over a decade, highlighting the remaining resource potential of this mature basin.

The well was drilled down dip of an isolated carbonate platform targeting the Hauptdolomit reservoir. Reservoir facies encountered at the well location are represented by grain-rich calciturbidites intercalated with fine-laminated mudstones interpreted to represent a slope depositional environment.

Preliminary petrographic evaluation shows a predominance of non-skeletal grains commonly derived from the platform area, with a relative abundance of ooids and coated grains and secondary intraclasts, aggregate grains and shell fragments. Visible porosity is moderate to good and predominantly in the form of molds associated with ooids, micro-vuggy and intraparticle porosity.

Diagenesis is inferred to control the RQ heterogeneity observed in the reservoir rock. While diagenetic overprint of the Hauptdolomit slope facies is widely documented across the Southern Permian Basin (e.g. Germany, The Netherlands, onshore UK), direct insights from the recently acquired dataset suggests that the paragenesis may differ from the expected trend. Learnings from the Pensacola discovery might shed new light on the Zechstein carbonate complexity with direct impact on reservoir productivity and possible future development.

Subglacial carbonates: unique archives of changes in glacial environments

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Rapid retreat of glaciers across the world is exposing subglacially formed carbonate crusts that can provide mineralogical and geochemical evidence about past glacier dynamics and subglacial environments.

Subglacial carbonates are mineral precipitates that form underneath ice sheets and glaciers, at the interface of the bedrock and the ice. These deposits commonly form at the lee side of bedrock protuberances. On the stoss side, basal water is generated by pressure-induced ice melting, which can dissolve the bedrock. The subsequent freezing of the water, when pressure is released on the lee side, results in concentration of ions, supersaturation relative to calcium carbonate of the residual water and subsequent precipitation of calcite or aragonite. $CaCO_3$ precipitation may also occur by freezing of meltwater transported from elsewhere in the subglacial system through interconnected pore/channel systems.

Subglacial carbonate crusts are a few mm to cm thick, with a fluted morphology parallel to the direction of the ice flow. The carbonate minerals may be associated with fine micrite detrital layers and, in particular redox conditions, to opal. Subglacial carbonate crusts are usually laminated and display both primary and diagenetic fabrics. Common fabrics are columnar or acicular, which may be organized in folded structures oriented downflow, which suggest glacially-imposed stress during crystal growth.

Environmental changes recorded by the geochemical, microbial, mineralogical and textural features of subglacial carbonates can be dated by radiometric methods, thus providing relevant information about past subglacial hydrology and processes in areas that are, now, deglaciated. Critically, the characteristics of subglacial carbonates appear to be related to the thickness, flow and characteristics of the subglacial environment at the time of formation.

Here we present petrographic and geochemical characteristics of subglacial crusts that formed at peak glacial conditions in diverse settings, and the environmental information that we can obtain from them. Examples include calcite and aragonite subglacial crusts from the European Alps, specifically Triglav (Slovenia) and Brenta Dolomites (Northern Italy).

Ancient groundwater ecosystems provide new evidence of microbially-influenced dolomite and Mg-clay mineralisation

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Groundwater systems are a major location of microbial biomass but have rarely been considered as environments for studying microbially-influenced mineralisation. Here we present our study that investigates the association between extracellular polymeric substances (EPS), dolomite and clay minerals within groundwater dolocrete profiles in arid northwest Australia. We found that EPS provided nucleation sites for both dolomite and authigenic clay minerals, including montmorillonite, trioctahedral smectite and palygorskite-sepiolite. Replacement and replication of EPS by clay minerals have preserved the EPS alveolar structures, encasing dolomite crystals. The dolomite developed as nanocrystals, likely via a disordered precursor, which coalesced to form larger micritic crystal aggregates and rhombic crystals. The ability of the negatively charged surfaces of clay and EPS to bind and dewater Mg^{2+}, as well as the slow diffusion of ions through a viscous clay or EPS matrix, may promote the incorporation of Mg^{2+} into the mineral and overcome the kinetic effects to allow disordered dolomite nucleation and its later growth. The results of this study show that the precipitation of clay and carbonate minerals in alkaline environments may be closely associated and can develop from the same initial amorphous Ca–Mg–Si-rich matrix within EPS. Local physicochemical changes, such as small increases in alkalinity, associated with the degradation of EPS or microbial activity, were likely important for both clay and dolomite formation. The abundance of EPS preserved within the profiles is evidence of past microbial activity; Pilbara groundwater aquifers are renowned for high biodiversity and endemic subterranean invertebrates (the stygofauna), are known to have been present in the period preceding and overlapping with the age of dolocretisation in the Late Miocene and Pliocene, indicative of a diverse ancient groundwater ecosystem. Microbially-influenced mineralisation may help explain the distribution of dolocrete in many inland drainage systems and has implications for models of groundwater dolocrete formation as well as the interpretation of mineral-derived information for palaeoenvironmental research.

Hydrological and microbial drivers of tufa formation in the Murujuga rock art province, northwest Western Australia

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Our study investigates tufa deposits from Murujuga (Dampier Archipelago), a significant rock art province in the coastal Pilbara region of northwest Western Australia. The tufa are of interest as palaeoenvironmental archives and as records of past freshwater sources that may have been available to, and influenced the movement of, Aboriginal people known to have been living in the region since ~50 ka.

Here we provide the first characterisation of tufa from Murujuga and present a depositional model that will form the basis for interpretation of palaeoenvironmental data. The tufa are distributed within ephemeral creek systems and include tufa barrages along broader areas of some creeks with larger cascade deposits, often several metres high, primarily in gorges and areas of elevation change where water flow can be turbulent. The creek systems are surface water-dependent, but some are supplemented by bank storage seepage following large recharge events. Our results show that microbial fabrics are dominant across all the studied tufas and that both hydrological and microbial processes are important for tufa formation. We discuss insights into past environmental and hydroclimatic conditions and processes based on the assessment of microbial textures and geochemical analysis of the tufa; this data includes conventional stable oxygen and carbon isotope data, alongside coupled strontium isotope ratios (primordial $^{88}Sr/^{86}Sr$ and radiogenic $^{87}Sr/^{86}Sr$) that will also inform on the source of Ca in the tufa, which are unusually situated within a meta-igneous bedrock terrain.

Radiocarbon age data has constrained tufa formation to the Holocene and indicates that formation coincides with wetter conditions in the mid-Holocene, following sea level rise and formation of the archipelago since the Last Glacial Maximum. Erosional processes and increasing aridity in the late Holocene appear to have reduced tufa formation during the past 2000 years. The outcomes of this study demonstrate the potential of tufa to inform on changing environmental and hydroclimatic conditions throughout the Holocene and contextualise the extraordinary archaeological record of this region.

Carbonate rock type prediction based on NMR logging responses: a case study of the Barra Velha Formation lacustrine carbonate reservoir from the Santos Basin, SE Brazil

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Rock type is an important step in carbonate reservoir characterization and geological model building for reservoir simulation as it helps to group zones with similar petrophysical characteristics. The pore systems of carbonate reservoirs exhibit high heterogeneity due to various processes during the sedimentation and diagenesis, such as compaction, cement formation, dissolution, and fracturing. Furthermore, lacustrine carbonates are formed in less stable environments resulting in more complex patterns vertically and laterally than most marine deposits, which makes it challenging to establish zones with comparable petrophysical properties. The Santos Basin Pre-Salt deposits are characterized by their lacustrine origin, and the Barra Velha Formation (BVR) (sag/post-rift), the focus of this work, is composed of three main components: shrubs (shrub crystals), fibrous laminae and spherulites, and derived detrital materials. Generally, the pre-salt reservoir has a wide variety of pore sizes and dissolution features characterized by dual porosity, such as matrix and non-matrix porosity. The main porosity is related to the matrix features and, in some cases, the non-matrix porosity is linked to a high content of silica and fractured zones. The present work represents an ongoing study, where we present preliminary results of the petrophysical evaluation using the rock types approach. The NMR logging (permeability and porosity measurements) from 16 wells located in different paleotopography domains combined with mineralogy, especially silica content from elemental spectroscopy tools, were used to define six petrophysical rock types (PRTs). The advantage of using the NMR carbonate rock type model is that it can be applied in non-cored sections, providing valuable input data to enhance the conceptual understanding of reservoir modelling. The PRTs were supported by borehole image log to avoid classification problems (e.g., zones with large-scale dissolution features), and any necessary corrections were made to ensure accurate results. As a preliminary result, it was observed that the reservoir PRTs are concentrated in the east side of the structural high, primarily associated with the Upper BVF, which contains substantial proportions of reworked carbonates and low silica content. Conversely, the west side is characterized by an increase in mudstone and spherulitestone facies content at greater distance from the structural high. The silica content increases near the fractures zones and is usually associated with non-reservoir PRTs. Implementing an integrated workflow that encompasses both seismic and morphometric interpretation, in conjunction with wellbore data is crucial to quantifying and conceptualizing PRTs.

Sedimentology of Aptian reworked carbonate deposits in the pre-salt reservoir of Santos Basin, SE Brazil

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The Santos Basin is the most prolific hydrocarbon producer of the pre-salt province, located southeast of Brazil, and is largely constituted by nonmarine and lacustrine carbonate sequences. The Barra Velha Formation (BVF) is the uppermost Aptian formation of Santos Basin, predominantly comprised of shrubby limestones, dolomudstones, intraclasts grainstones, and rudstones, as well as spherulitic and dolomitic Mg-rich silicate claystones, deposited in a shallow endorheic lacustrine environment. The BVF reworked deposits have been poorly studied, and there are still many gaps about their origin, provenance, and relationship with high Wells productivity. The present work aims to characterize these reworked carbonate facies and establish their genesis through a multi-scale approach. The methodology included data from different sources of a key well from Santos Basin, including: (1) petrology and petrography of core samples, (2) borehole image log (BHI) facies analysis, and (3) interpretation of 3D seismic data. The description of the core samples from the shallowest 40 m of the Upper Barra Velha Formation, allowed identifying nine sedimentary facies and microfacies grouped in two facies associations (FA): FA1 – Shallow lake deposits and FA2 – Lake-shore deposits (foreshore and shoreface). The FA1 comprises shrubstones, laminated spherulitestone/shrubstone, and laminated mudstone facies mainly composed of *in situ* carbonates reworked by wave influence. The FA2 includes grainstones with rounded pebbles and stratification ranging from plane-parallel to low-angle cross-stratification, grainstone with climbing and wavy ripples patterns, laminated grainstones, and massive rudstones. The detailed interpretation of inline and crosslines allowed the identification of two geometric patterns of seismic reflectors in the Upper BVF, high-amplitude onlapping seismic reflectors toward the basement and high-amplitude bidirectional-mounded shape on the edge of the platform, with a predominance of spherulitestones, shrubstones, and grainstones-packstones BHI facies. Rudstones-grainstones, mixed reworked carbonates/volcanic sediments BHI facies associated with the low-amplitude sheet-like shape reflectors dipping toward the slope seismic reflectors pattern were interpreted in this work as gravity flow deposits of fan-delta in the Lower BVF. In the Upper BVF, the rift lake constantly expands, favouring the lake dispersion and shallowing. Such an event is recognized by the migration pattern of the onlap to landward curves at the top of the stratigraphic profile.

Integrating fractures and dissolution features to predict reservoir connectivity of a pre-salt carbonate reservoir from the Santos Basin, SE Brazil

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In naturally fractured carbonate reservoirs, in addition to matrix heterogeneity, fractures are central to characterizing the connectivity distribution and super-K zones since they act as pathways for diagenetic fluids that often favour intense rock dissolution. Many times, fractured zones cause significant drilling fluid losses and are hardly identified in seismic due to the lack of resolution, making it a great challenge for hydrocarbon exploration and production. In the Santos Basin, SE of Brazil, the pre-salt carbonate reservoirs from the Barra Velha Formation are the main hydrocarbon producers in the country and are primarily formed by calcite shrub-like elements, spherulites, laminites, and reworked carbonate facies sealed on its top by the late Aptian salt sequence from the Ariri Formation. In some intervals, the pre-salt has a high fracture density and a wide variety of dissolution features such as vugs, conduits, and caverns which are frequently associated with fractured zones. In this work, the characterization of fractures was carried out using seismic and image log data to understand the influence of major faults and fractures in the non-matrix porosity development and to predict reservoir connectivity along the Barra Velha Formation. In general, the study area presents mainly NNE-SSW and NE-SW oriented major faults that compartmentalized it into different paleotopographic domains: High 1, Scarp slope, Dip slope, Wedge, High 2, and Western ramp, each of which with a distinct combination of open-fracture families. The fractures were formed during the rift fault reactivation, with mainly NW, NNE-NNW, NE, and ENE orientations, and were identified throughout the entire study area but with different density values. Fracture density is closely related to the distance from major faults. In the study area, those principal faults and wells with the highest fracture density are separated between 120 and 360 meters. The interpreted dissolution features indicate a preferential dissolution flow to the NE and NNE, and in minor cases to the ENE, especially in the Wedge domain. In general, large-scale dissolution features are present in wells with distinctive fracture families and in the vicinity of major faults. This work provides multiple scenarios of permeability distribution for the creation of conceptual models in pre-salt carbonate rocks that can be helpful with addressing uncertainties during oil exploration.

Multiphase diagenetic processes and facies distribution as controlling factors on carbonate reservoir properties

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The properties of carbonate reservoirs and their potential for CO_2 storage are heavily influenced by sedimentary facies, diagenesis and fracturing. Carbonates exhibit a wide range of porosity at various scales, from micro-pores to large vugs, creating challenges in the development of accurate petrophysical models. Therefore, successful carbon capture and storage requires a detailed understanding of the diagenetic processes as controlling factors of reservoir quality (i.e., porosity and permeability). In this study, the complex petrophysical properties of carbonate rocks deposited in a lower Jurassic shallow water carbonate platform (Calcare Massiccio Fm) have been studied on outcrop analogues, in several localities of the Umbria Marche Apennines (Italy). Various carbonate facies, deposited under different energy conditions from subtidal to supratidal settings, have been analysed to obtain a wide spectrum of data. The warm climate and the shallow depositional environment subjected these carbonate deposits to significant early diagenetic processes, which, combined with the effects of burial diagenesis, deeply modified the original texture, controlling the petrophysical properties. This study has been carried out throughout a multidisciplinary approach, including sedimentary facies and petrographic analyses combined with different techniques for porosity measurements, such as helium pycnometer and Synchrotron X-ray Micro-Computed Tomography (SR-µCT). Detailed sedimentary petrography and cathodoluminescence (CL) microscopy analyses have been performed, describing for each sample the rock-fabric, the porosity types, and the distribution and nature of different early and late cements. In addition, image analysis techniques, such as k-means clustering have been used to quantitatively measure the spatial distribution of calcite cement phases which variably reduced the primary porosity. The total and the effective porosities, which greatly affect the CO_2 storage potential of the reservoir, were measured using a helium pycnometer with an analytical accuracy of ≈ 0.001%. The SR-µCT have been performed to generate high-resolution 3D images, allowing an accurate quantification of pore size, pattern and connectivity. Preliminary results show that these shallow water carbonates underwent different stages of early diagenesis, including early marine dissolution and cementation, playing a fundamental role in preserving and/or destroying primary porosity. Carbonate types of cements, their luminescence, and distribution pattern suggest that mostly of porosity modification occurred during the early diagenesis and shallow burial, e.g., reducing the primary porosity of about 70% on average. Moreover, our data showed significant variations in fabric, pattern, and quantities of the early cements, depending on facies type and distribution. Further measurements of porosity and bulk density have revealed that the petrophysical behaviour of these carbonates is predominantly governed by their depositional environment, including early diagenetic processes, as well as the subsequent effects of burial

diagenesis and the formation of fracture networks. This study underscores the essential need to thoroughly assess the impact of both depositional and diagenetic processes on porosity and permeability to achieve more accurate predictions of reservoir quality, especially for highly complex and heterogeneous rock formations such as carbonates.

Distribution and significance of oolites through the Phanerozoic

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Marine carbonate ooids form in warm shallow waters, that are saturated or supersaturated with respect to calcium carbonate. To form they require an appropriate nuclei supply and a turbulent setting for CO_2 degassing. They occur in strata from the Archean to the Recent and form in a wide variety of shallow marine environments.

This study presents data collated from published literature on oolitic deposits covering the Phanerozoic to investigate their preferred platform type in each geological period of the Phanerozoic and the relationship between oolite production and the five major mass extinction events. Date evidence from 210 scientific publications reveals the importance of oolites on the sustainability of carbonate production during extreme environmental conditions that lead to biodiversity and ecological crises (e.g., Mass Extinction events) changing the nature of carbonate production dramatically. Extensive oolitic production occurred during three of the five mass extinction events in Earth's history. During the Frasnian-Famennian mass extinction event, the oolitic deposits increased threefold. During the most severe mass extinction event at the end-Permian, the oolitic deposits increased sixfold, and during the end-Triassic mass extinction event, oolitic deposits increased by 2.4 times. Notably, a significant temperature increase accompanied all three events. Noteworthy is that during the Late Ordovician mass extinction event, when extreme global cooling took place, no oolites were reported. And during the Cretaceous-Palaeogene boundary mass extinction, when the global average temperature dropped to 15 °C, preceded by global cooling, there were no statistically significant differences between the number of oolitic deposits before and after the event.

Our study is a preliminary attempt to examine the contribution of oolitic deposition to the development of platform architectures, especially in stressed climatic conditions and environments of the Phanerozoic Eon. Our findings provide tools for the prediction of stratigraphic architectures in underexplored areas.

Dolomitization models of an ICB of the Miocene carbonate play in Central Luconia, offshore Sarawak, Malaysia

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The Central Luconia geological province, situated approximately 100 miles offshore Sarawak, Malaysia, has been of interest to carbonate geologists for decades. This region has witnessed continuous oil & gas exploration, development, and production activities since the latter part of the 1960s. Encompassing an extensive area measuring approximately 45,000 km², the province comprises approximately 200 individual Middle to Upper Miocene isolated carbonate platforms. To date, substantial volumes of gas, surpassing 65 trillion cubic feet (TCF), equivalent to approximately 12 billion barrels of oil equivalent (BBOE) have been discovered. While exploration activities now focus on the smaller carbonate build-ups, the large fields are in decline and now considered for CO2 sequestration. The dolomitization of carbonate reservoirs in the Central Luconia region of offshore Sarawak, Malaysia, has been the subject of several studies as it affects reservoir properties and production behaviour. Various models have been proposed to explain this process. First, the Mixing Zone Model postulates that dolomitization in the Central Luconia carbonate reservoirs is linked to the mixing of seawater and hypersaline brines. Second, the Shallow Burial Model postulates that as sediments undergo progressive burial, increased temperatures and pressures facilitate the migration of magnesium-enriched fluids sourced from evaporites or seawater instigating dolomite precipitation. Lastly, the Hydrothermal Model is intrinsically linked to the circulation of hydrothermal fluids, wherein fault and fracture networks serve as conduits for the transport of magnesium-rich fluids and dolomitising fluids are sources from deeper sources. As these models would result in very different shapes and distributions of dolomitized bodies, understanding the dolomitization processes and their consequential impact on reservoir characteristics holds paramount importance in facilitating well-informed decision-making during field development and operations. The potential ramifications resulting from distinct dolomitization models encompass several aspects, including reservoir quality and heterogeneity, fluid flow behaviour, petrophysical properties, hydrocarbon distribution and entrapment, and the stability of wellbores.

The dolomitization in the Central Luconia carbonate reservoirs is likely influenced by a combination of these models, as the process can be complex and multifaceted. The relative importance of each model may vary depending on the specific geological conditions and local hydrological factors within the reservoirs.

This abstract/poster will provide an overview of some of the existing dolomitization models in this area and discuss evidence for and against each model, using PX-1 field, a low-relief carbonate pinnacle of Middle Miocene age located in Central Luconia, as a case study.

Challenges for Defining Electrofacies Models: the problem with Well Log Resolution and the Resulting "Shoulder Bed Effects"

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Electrofacies models are derived from well logs therefore relying on the log resolution. The electrofacies are limited to the maximum resolution of the least resolving input log, yielding unreliable results on beds thinner than the maximum resolution. Combining input logs with different vertical resolutions is another challenge in interpreting electrofacies as it increases the impact of shoulder bed effects. Logs with high resolution will react immediately to a boundary between two distinct lithologies showing a sharp response, while low resolution logs start reacting earlier to the lithology boundary and remain reading information from the first bed while already moving to the adjacent one. This process may lead to misinterpreted distinct facies, indicating the presence of thin beds that in fact do not correspond to the actual geology. Identifying and filtering out layers thinner than the log resolution is necessary for quality control of the electrofacies models and accurate geological interpretation. In this work, an unsupervised artificial neural network (ANN) based on self-organizing maps (SOM) was carried out to generate electrofacies to help in the zonation and characterization of a pre-salt lacustrine carbonate reservoir in the Aptian Barra Velha Formation, in Santos Basin, SE Brazil. ANN input data included gamma-ray, photoelectric factor, resistivity deep, sonic, neutron porosity, density, total porosity and effective porosity profiles from 21 wells, together with mineralogical models. A total of four electrofacies were defined from the ANN application and for the lithological characterization core descriptions and thin section images were used as complementary data. Considering the maximum vertical resolution as one meter, as defined by sonic log, two additional logs were created from the electrofacies propagated log, one removing electrofacies thinner than half a meter and the other eliminating electrofacies less than one meter thick. Electrofacies patterns from the full propagated log and the two corrected logs were correlated with the lithological observations from the additional data and, although some accurate information was lost, applying the electrofacies resolution quality control provided a more reliable geological characterization. This study is aimed to discuss the applicability of electrofacies for geological modelling and the resolution of electrofacies models depending on the logs used for generating the models.

Depositional age models in lacustrine systems from zircon and carbonate U-Pb geochronology

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Lacustrine deposits are extensively investigated because they play a pivotal role as environmental recorders and host valuable economic resources. However, chronostratigraphic reconstructions in these settings are usually hampered by the scarcity of data required to establish the depositional age of the system. The Yacoraite Fm. (Salta rift, Argentina) consists of Maastrichtian-Danian lacustrine carbonate and siliciclastic deposits with interbedded volcanic ash layers, organized in four third-order stratigraphic sequences. It offers the exceptional opportunity to jointly apply in situ zircon and carbonate U-Pb (LA-ICPMS) geochronology that resulted in two distinct depositional age depth models. Ages of the youngest zircon population from ash layers were linearly interpolated to derive a zircon depositional age (ZDA) depth model. A carbonate depositional age (CDA) depth model was instead obtained from dated carbonate phases including microbialites, ooids, oncoids of calcitic and dolomitic mineralogy as well as early lacustrine calcite cements. Mean ages were defined from different carbonate phases belonging to the same layer and then linearly interpolated to build a CDA depth model. Sedimentation rates were calculated from both depth models between pairs of dated samples and used to estimate the age of sequence boundaries, as well as the duration of the four stratigraphic sequences. The ZDA and CDA depth models agree with biostratigraphic constraints and exhibit excellent consistency. The onset and end of sedimentation were estimated at 68.2 ± 0.9 Ma and 62.3 ± 0.6 Ma (duration ~5.7 Ma) via zircon geochronology and at 67.9 ± 1.7 Ma and 61.9 ± 1.3 Ma (duration ~6.0 Ma) via carbonate geochronology. The time resolution of the CDA depth model (1.5-2%) is comparable with that from the ZDA depth model (0.9-1.4%) and revealed to be strictly dependent on the precision of the ages employed to build the model. In this respect, this study highlights that not all carbonates are dateable and specific precipitation processes, petrographic features and mineralogies may promote a higher dating potential in some carbonates (a poster with title 'The dating potential of carbonates for chronostratigraphic studies in lacustrine systems' is available on this topic). Results from this study show that with suitable samples and a newly implemented working strategy, in situ U-Pb dating of depositional and early diagenetic carbonates represents a valuable chronostratigraphic tool for estimating sedimentation rate and duration in poorly time-framed depositional systems.

The dating potential of carbonates for chronostratigraphic studies in lacustrine systems

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Carbonate U-Pb LA-ICPMS geochronology (LAcarb) demonstrated to be a valuable chronostratigraphic tool for estimating sedimentation rate and duration in poorly time-framed sedimentary systems. In the framework of the lacustrine Yacoraite Fm. (Maastrichtian-Danian, Salta rift, Argentina) 80 carbonate phases were analysed along a vertical section previously dated via zircon U-Pb geochronology (an oral presentation with title 'Depositional age models in lacustrine systems from zircon and carbonate U-Pb geochronology' is available on this topic). Results from this study highlight that not all carbonates are dateable and specific precipitation processes, petrographic features and mineralogies may promote a higher dating potential in some carbonates. Evaluating the dating potential requires to establish the dating success rate (% of carbonates providing a depositional age) and the age precision of various depositional and early diagenetic carbonates and mineralogies. This is of prime importance to boost the success of future LAcarb based chronostratigraphic studies.

A statistical analysis was conducted on the 80 carbonate phases from the Yacoraite Fm. previously analysed by LAcarb. Carbonates yielded a general dating success rate of 54% although microbialites revealed to be associated with the lowest dating success rate (41%) and age precision (uncertainty < 10%). In contrast, lacustrine cements provided the highest dating success (65%) and age precision (< 3%). Coeval calcite and dolomite phases provided the same dating success rate although dolomitic phases resulted generally associated with lower age precision. The carbonate dating potential was interpreted as an interplay of initial conditions of precipitation and preservation potential during diagenesis. Lacustrine cements precipitate in more reducing conditions if compared to microbialites. This facilitated U sequestration. In addition, the cements investigated are characterized by an equant crystal habitus with low reactive surface area that promoted preservation during diagenesis. The lower dating potential of microbialites in this specific case study do not only depends on the high reactive surface area typical of micrite-size crystals but it is mainly related to the high Pb content which is due the presence of clay particles trapped during microbialite formation. Dolomite is known to be more easily affected by diagenesis if compared to calcite. This induced homogenization of U-Pb isotope ratios and consequently lower age precision.

Results from this study provide new insights regarding the sequestration of U in carbonates from lacustrine systems and encourage to preferentially target early diagenetic calcites for chronostratigraphic studies based on the LAcarb technique in these depositional systems.

Facies analysis and depositional architecture of Eocene base-of-slope resedimented carbonate deposits, Gargano Promontory (Italy)

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The distribution and architecture of base-of-slope resedimented gravity flow carbonates can be challenging to understand due to the various and complex depositional processes involved.
In order to identify the triggering mechanism of gravity flow development, whether it is due to normal sediment export processes, slope destabilization, or tectonic-induced re-sedimentation processes, it is necessary to conduct a comprehensive analysis of the carbonate sediment composition. This analysis include an examination of detailed analysis of carbonate sediment composition, in terms of facies, spatial distribution and depositional architecture of these deposits. The Apulia Carbonate Platform (ACP) is a wide Mesozoic-Cenozoic isolated carbonate domains of the Tethyan Ocean that, during the Eocene, it went through an uplift and subaerial exposure causing regional unconformity, gravitational collapses, and massive deposition of slope and base-of-slope resedimented carbonates. These deposits, which are impressively exposed in the Gargano Promontory, consist of a basal mega-breccia (Grottone Megabreccia) and breccias with bioclastic turbidites (Peschici Formation), along with micritic limestones and pelagic marlstone. These deposits represent the basinward exportation of loose sediments from the Cretaceous and Eocene margins. Previous studies of these systems still leave many questions unanswered about the control factors that affect their depositional architecture and transport mechanisms acted on them. Thus, a detailed lithofacies map of the area was created to deeply characterize the facies and spatial distribution of these base-of-slope deposits in order to provide answers to these open questions and improve our scientific knowledge about these systems. Additionally, these studies can aid in the exploration of subsurface analogues by identifying and characterizing important oil and gas reservoirs, as submarine fans or aprons represent significant oil and gas reservoirs worldwide.

Upwelling as a control on regional distribution of heterozoan and photozoan carbonate facies in a low-latitude setting, Lower Mississippian, Continental U.S.

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Under ideal photic zone conditions, low-latitude shallow-water carbonate systems are generally dominated by photozoan association components. When the photic zone is perturbed, commonly due to excess nutrients, turbidity, and/or cooler water, the systems are characterized by abundant heterozoan association components and photozoan association components can be reduced or even absent (termed transitional carbonate systems). Compared to photozoan-dominated systems, transitional systems are still not well understood. Lower Mississippian carbonates in the U.S. form significant petroleum reservoirs and are potential targets for CO_2 storage. Our study is developing regional distribution patterns of shallow-water facies to provide a first-level understanding of controls on deposition and relevance to reservoir character. During the Early Mississippian, most of continental U.S. was in a low-latitude setting and various carbonate facies were deposited in a shallow tropical sea. Inner-to-outer ramp facies in areas bordering basins south of the Transcontinental Arch (TA) (Anadarko, Marathon, Arkoma, Illinois), and southeast areas flanking the Appalachians are dominated by heterozoans, including echinoderms, bryozoans, and brachiopods. Solitary rugose corals, siliceous sponges, biodetrital and Waulsortian mounds, and evaporites are locally abundant. Notably, areas south of the TA (STA) lack abundant photozoan components (minor occurrences of oolites locally). Heterozoan, biosiliceous and mound facies are also found in inner ramp and shelf areas west and north-northwest of the TA (WNTA). However, those areas also show significant abundances of photozoan components, consisting of red, green, and blue-green calcareous algae, stromatolites, benthic foraminifera, and oolites, including those surrounding basins (e.g., Williston Basin). Shallow-water colonial Rugosa and Tabulate corals are also common in WNTA areas. Previous paleogeographic and paleoceanographic studies interpreted upwelling in basinal areas, especially those south of the TA, during the Early Mississippian to account for the abundance of biosiliceous facies and other types of buildups in basin margin areas. The dominance of heterozoan and biosiliceous facies and lack of photozoan facies in shallow-water STA areas indicates adverse photic zone conditions, whereas facies with abundant photozoans in WNTA areas reflects more normal photic zone conditions in those areas. This facies distribution pattern is consistent with upwelling as a dominant source for nutrients, silica, and cool water south of the TA.

Halimeda bioherms from the upper Miocene reef of the Salento Peninsula, Southern Italy

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Calcareous green algae bioconstructions are receiving increasing attention from the scientific field as they represent a stratigraphic and palaeoecological archive comparable to that of coral reefs. Currently, the genus *Halimeda* spreads out from tropical to temperate environments and contributes significantly to the production of carbonate sediment due to its rapid calcification process. In some cases, *Halimeda* forms localized or extensive multi-kilometric bioherms such as in the northwestern part of the Australian Great Barrier Reef or in other tropical area of the Caribbean and Indian Ocean.
Despite their widespread occurrence in the Modern oceans, *Halimeda* bioherms are quite rare during the Cenozoic and show a discontinuous stratigraphic distribution. As a matter of fact, these bioherms are reported only into carbonate Messinian pre-evaporitic successions and in very few localities around the Mediterranean Sea.
In this study, we present data carried out from stratigraphic and sedimentological analysis of two *Halimeda*-rich deposits reaching maximum thickness of 5-6 m, located in the southernmost margin of the Salento Peninsula (Apulia Carbonate Platform) inside the Novaglie Formation. Two stratigraphic sections were sampled and taphonomic observations were applied across the *Halimeda* beds. These deposits show marked basal contacts, while the upper is gradual with a transition that takes place over a few decimetres. After field observation integrated with thin section analysis, seven facies have been identified with textures spanning from boundstones to packstones in which the fauna is mainly represented by *Halimeda*, other encrusting organisms like vermetids, serpulids, red algae and acervulinids, bivalve shells and corals. The *Halimeda* boundstone, in particular, is mainly composed of thalli in growth position in a fine packstone/wackestone matrix with few other bioclasts. This facies is divided in two sub-facies, one of which shows very well preserved algal segments rimmed by up to four generations of cements filling the high intergranular porosity.
The presence and developments of these small bioherms seems to be linked to the occurrence of nutrient-rich cool waters related to upwelling currents. Such upwelling events are not unusual in the stratigraphic record of the Salento Peninsula, as documented by the deposition of the condensed phosphatic-rich sediments (Aturia Level) during the Serravallian-Tortonian. Furthermore, nutrients supply through the upwelling currents seems to be the main control factor on the developments of the extensive *Halimeda* bioherms of the Great Barrier Reef.

Fluvial barrage tufa as a natural lab for the improving of geotechnical engineering properties of sand by Microbially Induced Calcium carbonate Precipitation (MICP)

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In the last two decades one innovative approach to decrease the harmful impact on the natural environment, is to use microorganisms to produce sustainable biomaterials, such as microbially induced Ca-carbonate precipitate (MICP). MICP has been studied for ground improvement to enhance shear strength and stiffness after introducing Ca-carbonate cementing agents into the pores, and for other applications including environmental remediation, production of construction material, improved durability and remediation of building materials, cations removal in wastewater, and carbon sequestration. However, even if MICP could represents a good alternative to the utilization of natural resources and to reduce CO_2 and NO_2 emission of industrial activities, the process produces an inevitable environmental impact as the waste and chemicals involved in lab activities. With the aim to develop a bio-cement for increasing the geotechnical properties of a common multimineral sand, a more sustainable process of MICP was tested introducing the sand in the water flow of a tufa-forming river with active microbial Ca-carbonate deposition. The tufa deposits are covered by a lithifying biofilm composed of a microbial community including autotrophic and heterotrophic bacteria, algae, viruses, and extracellular polymeric substances. Biominerals forming the tufa deposit replace the organic substrates starting with an amorphous phase rich in Ca, Si, and other cations, followed by massive precipitation of fibrous to polyhedral Ca-carbonate crystals and subordinately lamellar/fibrous Mg-clay crystals. During the 16 weeks of the experiment, the biofilm colonized rapidly all the surface of the sand grains, which were gradually encrusted by neoformed Ca-carbonate biominerals showing the same crystal structures and composition of those forming the tufa deposit. Moreover, the sand showed a progressive increase of the internal friction angle from 28,6° to 35,4°, with a trend very similar to MICP lab experiments that used a single bacterial species. This suggests that is possible to use natural Ca-carbonate biominerals, induced by natural microbial communities, for engineering applications with very sustainable procedures.

Using SST-proxy data from the Coral Sea to reevaluate carbonate facies models and long-term changes in coral reef systems

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The Queensland Plateau in the Coral Sea has one of the best-constrained geologic histories of coral reef expansion and demise since the Early Miocene. In 1991 an ODP expedition took cores aiming to reconstruct both the carbonate facies history and the causes of reef development and decline in the Coral Sea. Based on this and using $\delta^{18}O$ isotope data to reconstruct sea surface temperatures (SSTs), they suggested that a Late Miocene cooling between 11-7 Ma (20-18 °C) caused coral reef loss followed by Mid-Pliocene warming leading to the restoration of reefs between 3.5-2.5 Ma. Further warming then led to the establishment of the Great Barrier Reef during the Mid-Pleistocene around 0.6 Ma. However, since this expedition, it has been shown that the $\delta^{18}O$ proxy used to reconstruct SSTs is susceptible to post-depositional alteration, especially in carbonate settings. Many other SST-proxies that have been developed since have either been shown not to work in carbonate environments or thought to be non-ideal for reconstructing SSTs from sediments bearing low TOC. As a result, there has been a poor understanding of the role that paleo-SSTs played in coral reef development and how changes in temperature influenced carbonate environments in the past. In this project, we have managed to reconstruct a biomarker SST proxy record (TEX_{86}) at two sites, ODP 811 (from 11-2 Ma) and ODP 820 (from 0.9-0 Ma), to try and understand the role that SSTs have played in changing the environment of the Coral Sea. In doing so, we showed that the Late Miocene Coral loss was associated with warm, not cold SSTs leading to a reinterpretation of the facies model for this period. However, some of the facies change, especially in the Pliocene, relate to changes in SSTs. Furthermore, we show that coral reef development in the Pleistocene closely follows changes in SSTs. This suggests that changes in SSTs did play a key role in changing environmental conditions in the past. Given the impact of future warming on these tropical carbonate platforms, we must understand the role of SST changes on critical environments such as coral reefs. Therefore, we see a strong potential to better understand the future threshold responses of carbonate environments to temperature changes.

The sequence stratigraphy of a heritage stone: lower Oligocene Vicenza Stone and the expansion of Antarctic ice

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Andrea Palladio (1508-1580) is universally considered one of the fathers of architecture. He began as a stonemason in Veneto, north-eastern Italy. As an architect, he made extensive use of local stones – the most distinctive of which was a porous limestone of early Oligocene age, that could be easily dimensioned and carved. Nowadays, this stone is sold as "Pietra di Vicenza" (Vicenza Stone), and often advertised as "the stone of Palladio".

Vicenza Stone was quarried in the Berici Hills and eastern Lessini Mountains, and forms 4-35 m thick massive horizons at multiple stratigraphic levels within the Castelgomberto formation, a lower Oligocene carbonate or mixed unit deposited on the Lessini Shelf, which was a wide carbonate platform and structural high, inherited from the Jurassic rifting of the Adria Plate. The stone was cultivated in subterranean quarries; the most renowned is known since Roman times at least, and exploits a ca. 35 m thick horizon at Costozza. Other horizons occur throughout the Castelgomberto formation, but are much thinner and their use in historical monuments is less documented.

We show that the Vicenza Stone grainstones have skeletal associations that can be attributed to nearly all sub-environments of a carbonate ramp, on the base of microfacies analysis of samples from 43 quarries covering the whole outcrop area of the stone. We found 4 neatly distinct microfacies: with articulated red algae and miliolids; with encrusting foraminifera and red algae; with articulated red algae and larger benthic foraminifera; with rhodoliths and encrusting red algae. These microfacies may be used to constrain the provenance of historical stone samples to a restricted set of quarries.

The Castelgomberto Formation lies everywhere over a paraconformity surface, formed due to a glacio-eustatic sea-level fall in the earliest Oligocene. Vicenza Stone in Costozza lies right above the paraconformity, quickly closes landward - likely against a fault scarp, and features a microfacies with articulated red algae and miliolids. Above, grainstones quickly pass to marly limestones and marls with rhodoliths. We interpreted this rapid and deepening-upward facies change as a transgressive surface, and then, the Vicenza Stone grainstones of Costozza as a Lowstand Systems Tract. Vicenza Stone thus have a double story to tell: as a heritage stone, it took part on the history of architecture; as a sedimentary body, it testifies for the response of shallow water carbonate depositional systems to the sharp sea-level fall at the early Oligocene expansion of the Antarctic ice sheet.

Dolomite recrystallization as identified through Mg-C-O isotope systems: a case study of Lower Ordovician dolomite from Yong-An-Ba Dam, Tarim Basin

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Widespread replacement dolomite commonly occurs in the geologic record. These dolomites are generally characterized by different crystal sizes and shapes that have at times been interpreted to represent multistage dolomitization; although the variation of dolomite texture could also have resulted from the recrystallization of precursor dolomite. It is important, but challenging, to differentiate these two scenarios to better understand the nature of dolomite and the associated processes of dolomitization. Our study explores this problem by using Mg-C-O isotope systematics to characterize the different crystal morphologies exhibited by Ordovician dolomites from Yong-An-Ba Dam, the Tarim Basin, China.

Although the dolomites show distinct textures and crystal morphologies, there are no discernible trends in their δ^{26}Mg values (from -1.66 to -2.39‰), suggesting that these dolomites were formed by the same dolomitizing fluid. This interpretation is supported by an overlapping range of δ^{13}C values (from 0.46 to -1.89‰). By contrast, the δ^{18}O data demonstrate a wide range of values, from -3.8‰ to -8.8‰, reflecting the different degree of recrystallization with increasing burial temperatures. We suggest that the Mg and C isotopes remained unchanged during recrystallization because Mg and C were rock-buffered, so the recrystallized dolomite inherited Mg and C from the precursor dolomite. Based on these results, it appears that Mg isotopes, together with conventional O-C isotopes, can provide a diagenetically robust geochemical tracer for identifying dolomite recrystallization in the geological record.

Unlikely (sea)bedfellows? A possible link between cold seep carbonates and localized diatomite deposition, Valhall overburden, southern Norwegian North Sea

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Since the discovery of the giant Valhall Field in 1975 it is known that the overburden contains large amounts of hydrocarbons that have escaped the deeper, Upper Cretaceous chalk reservoirs. Secondary oil accumulations are found in high-porosity / low-permeability, mid-Miocene diatomaceous mudrocks of the Lark Formation, interbedded with shales and locally with carbonate-rich intervals. The Miocene succession can be correlated regionally on seismic within a bio- and sequence stratigraphic framework. Seismic isochore mapping, calibrated to well data, highlights that some diatomite-rich intervals show local thickness maxima across Miocene palaeohighs, whereas others seem to have rather constant thicknesses.

In the crest of the Valhall Field, locally thickened diatomaceous mudrocks are interbedded with carbonate stringers ("pavements") and abundant carbonate concretions, as well as locally appearing mudstones that display a high gamma-ray log response. Core analysis reveals that the Lark Fm. carbonates show many similarities with published examples of modern methane-derived authigenic carbonates (cold seep carbonates). With a large gas cloud in the shallow overburden visible on seismic, it is evident that natural gas must have escaped from the deeper reservoirs in the not-so-distant geological past. In addition, charge modelling confirms that hydrocarbon migration into the deeper chalk reservoirs was in full swing during the Miocene, supporting the possible presence of methane seeps on the Miocene seafloor.

Thickening of diatomite deposits over palaeohighs has been proposed to result from local upwelling, with upwelling being caused by the deflection of ocean bottom currents. Based on the co-occurrence of seep carbonates and local diatomite deposition, we propose an alternative model for the Valhall Field, with bubble plumes rising from sea floor above as the main driver for local upwelling.

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Linking facies and Carbon stable isotope signature across the Triassic-Jurassic transition (Lombardy Basin, Italy)

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A cascade of important environmental perturbations characterized the Triassic/Jurassic transition associated with the opening of the Central Atlantic Magmatic Province (CAMP). In particular, the injection of volcanic CO_2 in atmosphere triggered ocean acidification and the End Triassic Extinction (ETE), which consisted in a major loss of carbonate shell taxa and the most severe crisis of scleractinian corals. This extinction event is commonly included among the five major mass extinctions of the Phanerozoic.

In the Lombardy Basin, the demise of the Rhaetian fauna is associated with abrupt facies changes, from marl-limestone cycles with corals, bivalves and foraminifera (Zu Limestone) to bedded and bioturbated mudstone and marly mudstone (Malanotte Formation) overlain by progradational ooidal shoals (Albenza Formation). The demise of the skeletal facies of the Zu Limestone and the rapid transition to mudstone and marly mudstone record a sea-level rise, followed by the return to shallower conditions with the ooidal grainstone of the Albenza Formation. Detailed sampling for inorganic and organic Carbon isotope chemostratigraphy was performed along three logs and compared with the facies types, in order to verify possible relationships between Carbon isotope trends and facies associations. An interval characterized by lower values on average (i.e. -27,3 ‰ vs -27‰) in the $\delta^{13}C_{org}$ was observed across the entire Malanotte Formation and a negative shift in the $\delta^{13}C_{org}$ curve occurs some meters above its base (8 m approx.). However, the range values are roughly comprised in between -25,2 and -28‰, the amplitude of the negative shift is limited to 1-2 ‰, and the three distinct Carbon isotope excursions reported in the literature (i.e. Praecursor, Initial, and Main) are not always clearly recognized in the studied sections. Furthermore, although $\delta^{13}C_{carb}$ and $\delta^{18}O$ show pristine values excluding burial diagenesis resetting, some changes in the $\delta^{13}C_{org}$ values seem to be related to the different facies types. A possible facies control on the $\delta^{13}C_{org}$ (especially in shallow-water conditions) is thus plausible preventing a reliable correlation of the studied logs with those available from published literature. Correlations of T/J boundary successions should thus require detailed facies analysis linked to the organic and inorganic Carbon and Oxygen isotope values, in order to identify lithofacies effects that may influence the stable isotope signature of marine carbonates, masking the global changes or inducing isotope shifts actually related to local conditions, partly detectable with detailed facies characterization.

Settling behaviour of natural carbonate sand-mud suspensions

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This experimental study addresses the settling behaviour of carbonate sediment suspensions, which display different hydrodynamic behaviour than siliciclastic suspensions due to a much wider range in grain size, shape and density of bioclastic grains. The grain-settling experiments used natural non-cohesive tropical carbonate sand from Moorea (French Polynesia) and natural cohesive tropical carbonate mud from the slopes of Little Bahama Bank. Bulk settling deposits were studied for sediment concentrations of 9%, 20% and 30% and deployed varying carbonate sand-mud mixtures. Laser diffraction analysis and microscopic analysis revealed distinct textural trends throughout all experiments, from base to top: Interval A, fairly ungraded pack- to grainstone and rudstone, occasionally with a fining-upward base for low bulk concentrations and mud proportions; Interval B, normally graded grain- to packstone; Interval C, normally graded wackestone to mudstone. Interval B deposits are least muddy (cleanest sand), yielding the best sorting and high porosity values. The normalized thickness of interval B is more or less constant for all experiments and does not seem to depend on sediment concentration or mud proportion. Interval C, on the other hand, thickens at the expense of interval A with increasing mud proportion. This trend becomes less pronounced for higher-concentration suspension deposits, for which interval A is the dominant facies. The ungraded part of interval A is underlain by a fining-upward base in deposits of low-concentration suspensions, the normalized thickness of which decreases with sediment concentration and mud proportion. The experiments demonstrate that grain-size segregation becomes less efficient with increasing sediment concentration and cohesive mud proportion. Thus, the presence of cohesive carbonate mud lowered the critical sediment concentration at which grain-size segregation starts to be suppressed, as revealed by thick ungraded interval A deposits. These observations suggest that variations in grain-settling intervals for calcareous suspensions are heterogeneous in nature (grain-size, biota); this may be related to the heterogeneity of the natural sediments used. Grain-size segregation is suppressed at lower sediment concentrations than for their siliciclastic counterparts, however, the variety in grain-sizes may have directed this trend.

Orientation of Late Pleistocene MIS 5e Bahamian aeolianites as records of geostrophic flow during the last interglacial

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Islands of the Bahamas-Caicos archipelago form an equatorial transect spanning >950 km in length and 6° of latitude. Island topography is primarily constructed from carbonate aeolian dunes that were deposited during interglacial phases of the Late Pleistocene and Holocene. The geomorphology of coastal dunes is influenced by the direction and variability of onshore winds, sediment supply, shoreline position and degree and style of vegetation which in turn can inform atmospheric circulation models and paleoclimate reconstructions. Most previous studies on Bahamian aeolianites have focused on outcrops exposed along roadcuts and sea cliffs that afford a detailed window into dune architecture but are relatively limited in spatial extent. Dense island vegetation masks topographic features and limits the utility of satellite imagery for geomorphological mapping of island interiors. Digital elevation models built from TanDEM-X satellite radar interferometry data reveal thousands of parabolic coastal dunes along the windward islands of the Lucayan archipelago presenting an opportunity to build on outcrop studies with whole-landform visualization. Geomorphological mapping of digital elevation models combined with object-based image analysis (eCognition, Trimble) defined a total aeolianite area of ~1674 km^2 across Great Abaco, Eleuthera, Cat, San Salvador, Long, Crooked, Acklins, and Mayaguana islands (Bahamas) and the Turks and Caicos Islands. Longitudinal axis measurements from 747 Pleistocene parabolic dunes record increasing consistency of east-west orientation with decreasing latitude. Three U.S. National Data Buoy Center data buoys provided modern wind direction and velocity measurements (n = *730,933* of each) along this transect. Analysis of wind vectors (>P90 [90th percentile], n = 70,095) demonstrates increasing organization of easterlies at southern latitudes similar trends observed in Pleistocene Marine Isotope (MIS) 5e deposits although there is a slight offset between the datasets. Findings from this study imply that major trends in regional dune orientation are a product of aeolian sediment transport flux, which increases from the edge of the horse latitudes (Great Abaco) to the trade winds (Turks and Caicos Islands). Increasing strength and consistency of directionality at southern latitudes is driven by geostrophic flow within the Hadley cell and right-hand deflection of the Coriolis effect. We propose that the slight offset in directionality between dune axes and modern wind vectors is related to changes in latitudinal width of the Hadley cell from the Late Pleistocene (MIS 5e) to today.

The emergence of pelagic calcification in the Upper Triassic and its influence on seawater chemistry

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Calcareous nannoplankton is the most productive calcifying organism nowadays and has a tremendous influence on the climate and the seawater chemistry, as a biological pump and as a regulator of surface ocean alkalinity. Modelling studies neglected this group as a potential influencer before the Jurassic, while first quantitative paleontological studies suggested that already before the Triassic-Jurassic boundary, calcareous nannofossils reached rock-forming abundance and influenced the oceanic system. This contradiction and the rare quantitative abundance data of the calcareous nannofossils in the Late Triassic indicated that further investigations were required to verify the hypothesis that the development of the calcareous nannoplankton had a significant influence on the seawater chemistry already in the Late Triassic i.e. at an early stage of their evolution. We investigated therefore quantitatively the calcareous nannofossil assemblages by light and scanning electron microscope in six Austrian and one Romanian sections (25°N), one section from Turkey (palaeo-equator), six sections from Oman (20°S) and one in Australia (30°S). In parallel, geochemical analyses were performed first with trace elements concentration to evaluate the impact of diagenesis on the preservation of the sediments and calcareous nannofossils but also to trace changes in weathering rate during the Late Triassic. Second, isotopic measurements were performed for strontium, calcium, carbon and oxygen to better constrain the environmental conditions during the early evolution of the calcareous nannofossils.

The nannoliths dominate the assemblage but are still a minor component of the rock during the Norian. they increase slightly in abundance in the lower and middle Rhaetian and reaches rock-forming abundance only in the upper Rhaetian. The coccolithophorids are present in low abundance, increasing slightly in the middle Rhaetian. The first coccolithophorids show a rather slow temporal diversification with ~ 4 million years for three species. The isotopic proxies revealed important palaeoenvironmental changes. The $^{87}Sr/^{86}Sr$ and $\delta^{44/40}Ca$ isotopic investigations highlighted the possible role of carbonate and evaporite dissolution on the chemical composition of the seawater due to a major sea-level fall just after the Norian-Rhaetian boundary. On the contrary, the longer-term $^{87}Sr/^{86}Sr$ and $\delta^{13}C$ isotopic trends are compatible with the incipient break-up of the Pangea supercontinent.

By the comparison of the calcareous nannofossil abundance and isotopic composition results, no clear correlations were observed. Carbon and calcium isotopic composition could be theoretically influenced by the increasing proportion of calcareous nannofossils in the sediments. Therefore, in lack of correlation, it can be said that their importance in global geochemical cycles remained limited in the Late Triassic and they contributed to shifting the major carbonate production from the shallow seas to the open marine realm only during the Jurassic.

Depositional context of the Balbuena III Sequence (Maastrichtian/Danian) in the Salta Basin, Argentina: integrated approach from sedimentological, stratigraphical and digital outcrop models

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The Salta Basin, located in northwest Argentina, was associated with the breakup of Gondwana during the Cretaceous period. It is subdivided into four sub-basins (Lomas de Olmedo - east; Sey - west; Tres Cruces - north; and Metán-Alemania - south) that were filled with sediments from Pirgua (synrift phase) and Balbuena (sag phase) supersequences. The sag phase is divided into four sequences: Balbuena I, II, III, and IV, from bottom to top. This research presents an integrated approach combining traditional and digital methods to characterize the sedimentology and stratigraphy of the Balbuena III Sequence (Maastrichtian/Danian) of the Yacoraite Formation in the Metán-Alemania sub-basin, Cabra Corral dam region, Coronel Moldes district, Argentina. Field data, including samples for petrographic and sedimentological analyses, were collected from vertical stratigraphic profiles, along which gamma-ray spectral records were also acquired. Finally, digital models of three outcrops were generated using aerial photogrammetry obtained by an unmanned aerial vehicle (UAV). They served as support for automatic processing of their geometry (roughness) and texture to interpret the observed facies and cycles on different scales. In the studied outcrops, the Balbuena III Sequence ranges from 28 to 33 m in thickness and consists of carbonate, siliciclastic, and mixed facies deposited in a lacustrine environment, whose climate was the main depositional controller. The carbonate facies include oolitic/bioclastic grainstones, oolitic/bioclastic packstones, bioclastic rudstones and floatstones, carbonate mudstones, laminites, and stromatolites. The siliciclastic facies comprise very fine wavy sandstones, siltstones, and siliciclastic mudstones. Mixed lithofacies deposition consist of hybrid sandstones and marls. The lithofacies have been grouped into four facies associations and two vertical successions of facies (elementary cycles). The observed cycles have been ranked into sequences of high, middle, and low frequencies and could be traced for tens of kilometres in the basin. These cycles have been also highlighted by numerical outcrop processing. First, the LBP (Local Binary Pattern) operator computed from the grey scale of the outcrop texture proved to be robust in identifying changes in lithofacies. Second, the fractal dimension was estimated from local variogram fitting and used as a tool for analysing the surface roughness. It allowed the identification of different lithological types, as they present distinct granulometries and responses to weathering. The combined analysis of field data and digital outcrop models makes it possible, in addition to understand the stratigraphic framework of the Basin, to map the cyclicity in areas of difficult or impossible access, such as cliffs and escarpments.

Current pathways in Rudist-dominated Upper Cretaceous shelves. Case studies from the Adria Promontory

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Shallow-water, late Cretaceous, rudist-rich limestones have been studied from vary localities in southern Italy and Croatia in which outcrop conditions show an excellent overview of the lateral and vertical evolution of rudist bodies and allow their geometry and the dynamic aspects to be reconstructed. Rudists gave rise to wide biostromal bodies and supplied most of the skeletal debris via bioerosion and minor physical breakdown. The evolution of rudist lithosomes was controlled by the environmental hydrodynamic conditions.

The stratigraphic architecture and facies characteristics suggest open depositional settings such that facies transition is very gradual and the facies belts are broad, while deposits related to distinct wave-resistant biogenic frameworks are absent. In such a depositional system the sea bottoms were presumably characterized by a low bathymetric slope on which the wave energy was dissipated along a wide shelf, resulting in a general low-energy environments. As a consequence the storms were low effective, with waves dampened for clutch on the bottom, testified from the maintenance in situ of the fine fraction, from the spread of lithosomes with rudists maintained in growth position and from the overall good preservation of the reworked bivalves, often still conjoined. The gross lenticular geometry of the shell beds could be related to the above-mentioned patterns of weak, maybe channelized, currents and/or pathways. In most cases, in fact, lithosomes can be considered as a multistorey growth in channel-like systems in a persistently subtidal setting.

Tidal currents and/or events of greater energy resulted in currents of preferential flow that created a network of small channel-like depressions along which the vivifying effect of the flows allowed the colonization and the survival of the rudists, also along the edges of the channels. The flow zones, instead, came overwhelmed from shells only weakly displaced.

Facies and depositional models of isolated shallow-water carbonate platforms: the Eastern Mediterranean archive

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In recent years, carbonate rocks have been the spotlight of several hydrocarbon fields and discoveries in the Eastern Mediterranean. The area is particularly prone to exploring long-lived shallow-water carbonate platform systems. Subsurface data, such as wells and seismic imaging, offer the chance to explore exceptionally preserved records of isolated shallow-water carbonate systems developed during Mesozoic times. The control on facies character and distribution exerted by the evolving geodynamic setting along with the changing carbonate factories makes this area an interesting subsurface laboratory. The absence of suitable outcrop analogs supporting the subsurface data makes studying these carbonate systems even more fascinating, although challenging, especially for prediction of their reservoir distribution.

The aim of this contribution is to show examples of facies types and their related depositional architectures in the framework of the buried Mesozoic isolated shallow-water carbonate of the Eastern Mediterranean domain. In detail, we show multiscale examples of such systems constituted by isolated ramp platforms, without rimmed margins, generally structurally controlled, locally punctuated by patch reefs, and developed within the frame of tropical carbonate factories. In such complex settings, a relationship between the involved geological parameters is not straightforward and does not fit existing models.

Travertines of mixed-water origin: insights into facies and geochemistry

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The facies variation of travertines that occupies Čerená hill (Liptov Basin, northern Slovakia) reflects the evolution of travertine growth conditions and therefore palaeoenvironmental and palaeohydrological conditions. The travertine buildup is underlain by conglomerates cemented with calcium carbonate. The clast composition points at the drainage of the nearby Low Tatra Mts to the north by surface streams. Early stage of travertines deposition is represented by laminated crust and micritic lithotypes. These lithotypes are vertically replaced by phytoclastic travertine with some calcareous mud layers. The latter have significant admixtures of clay minerals and quartz that results in reduction of calcium carbonate content. $\delta^{13}C$ values of the studied travertines fall in the range between 2.22‰ and 5.24‰, which indicates the role of deep-seated CO_2 in the depositional system and most probably deep-circulation water. The depletion of the $\delta^{13}C$ in phytoclastic travertine and calcareous muds is followed by reduction in calcium carbonate content. This suggests the dilution of deep-circulating water by meteogenic water fed with biogenic CO_2 of soil origin. Therefore, we conclude that above-mentioned lithotypes are of the mixed-water origin. U-series dating shows that the development of Čerená travertines started between 1.2 and 0.5 Ma. The deposition of travertines has ended approximately 0.2 Ma. This date coincides with the paleomagnetic reversal noted in the topmost layers of travertine buildup and it is most likely associated with the Jamaica-Pringle Falls excursion that occurred around 211 ka.

Textural controls on acoustic velocity in dolostones

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Dolomite reservoirs are significant hydrocarbon reservoirs in several parts of the world. Unrevealing the main controls on their seismic behaviour is a crucial aspect for hydrocarbon exploration, or for delineating the suitable zones for CO_2 storage. In this study, 100 dolomite samples, from five different formations, were used to investigate the main factors that control the acoustic velocity in dolostones. Samples were collected from strata that crop out in Eastern, Central, and Northern Saudi Arabia. Collected samples were slabbed, plugged, and thin-sectioned for petrophysical and petrographic analysis. Porosity and permeability were measured for the 1.5-inch plugs, using gas expansion technique at 500 psi pressure. Acoustic velocities were measured for the plugs at variable confining pressures; 1, 2.5, 5, 10, 20, and 40 MPa. The petrographic analysis included lithology, grain/crystal size, pore type, and pore size. SEM analysis was used to characterize the microstructures such as pore throats and microporosity. Mineralogy was determined using XRD analysis on powdered samples for the entire dataset. The studied samples show that porosity is inversely related to the measured velocity with $R^2 > 0.8$. In addition to porosity, the dolomite texture (fabric-preserving / non-fabric preserving) plays a major role in controlling velocity and deviations from the general porosity-velocity trendline. At porosities exceeding 15%, samples with non-fabric preserving texture show lower velocities compared to samples with fabric preserving texture. This is mainly attributed to the dominance of moldic, vuggy and interparticle pores in the fabric preserving dolomites compared to intercrystalline pores in non-fabric preserving dolomites. At low porosities (<15%), there is no clear distinction between fabric- and non-fabric preserving dolomites. This is due to the dominance of microporosity in both fabric- and non-fabric preserving dolomites. Mineralogical analysis shows that most of the studied samples are dominated by dolomite (>85%), and therefore, mineralogy has no clear impact on velocity. The outcome of this study might help in understanding the seismic behaviour of dolomite strata and the interpretation of sonic logging data in dolomite reservoirs.

Carbonate saturation state vs carbonate production rates in the geological past: in search for a paradigm

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Saturation state with respect to carbonate (Ω) plays a crucial role in influencing carbonate precipitation in seawater, which is one of the fundamental processes of the global inorganic carbon cycle. It has been shown that a broad positive correlation exists between modelled variation of Ω in the past and the abundance of carbonates in the geological record. With the goal of investigating further the influence of Ω on the calcification process in the oceans, we have examined several carbonate platforms, with age ranging from the Devonian to the Neogene, and estimated an average carbonate production rate (G, expressed as a mass/unit time/unit surface) for each case study. This task required estimating the volumes of carbonates deposited in selected time intervals, and hence, platforms were chosen for being well age-constrained and for the good outcrop conditions. The investigated platforms cover nearly 400 Myr of the geological record and are characterized by significantly different carbonate factories and modes of carbonate precipitation.

We are aware that a number of factors (e.g. the existence of hiatuses) can affect such type of calculations; however, we coped with them by applying some corrections, where possible. For instance, a correction factor was applied to G estimates based on the evidence that the longer the time interval considered, the lower the observed accumulation rates because larger hiatuses are incorporated.

When G estimates for the considered carbonate platforms are plotted in a log/log graph as a function of modelled Ω variations in the geological time (Ridgwell, 2005), they appear aligned and identify a logarithmic relationship. Such relationship closely resembles, and displays similar slope to, the empirical kinetic law that links G and Ω. A significant difference observed, however, is that Gs attained by carbonate platforms are higher than those predicted by the empirical kinetic law.

Results of our investigation suggest that a power law linking G and Ω may govern precipitation in shallow water carbonate systems regardless of the organisms involved and, therefore, Ω could have been the main driver of global calcification in the geological past.

The higher Gs attained by carbonate platforms with respect to those predicted by the empirical G/Ω kinetic law are consistent with laboratory evidence that biologically-mediated calcification occurs at higher rates than inorganic precipitation. However, the fact that this is here observed considering ancient carbonate platforms dominated by different organisms, suggests that this biotic effect may be due to mechanisms that could be ecology-independent.

Integrated petrographic, geochemical and isotopic studies on Aptian Pre-Salt deposits, Santos Basin, Brazil

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The Aptian Barra Velha Formation (BVF) of Santos Basin represents one of the most important hydrocarbon reservoirs in the world, responsible for most of Brazilian production. The unit also attracts great interest due to its unique composition and to its record of the initial, Pre-Salt evolution of South Atlantic Ocean. Several studies have been published about these lacustrine deposits regarding their origin, controls and reservoir quality.The aim of this work is to identify lithotypes with geochemical logs and X-ray fluorescence (XRF) data based on petrographic analysis and to provide further information on the geochemical conditions of the lake using $^{86}Sr/^{87}Sr$, $\delta^{18}O$ and $\delta^{13}C$ isotopic analysis. The BVF is composed of *in situ* and reworked lithotypes, with the former constituted by a mixture of calcite fascicular shrubs and spherulites, and Mg-clay matrix, and the latter formed by intraclasts from reworked carbonate aggregates. The study of approximately 300 thin sections of two wells from a Santos Basin oilfield showed that the best reservoirs are intraclastic calcarenites and calcirudites, followed by *in situ* shrubstones, both lithotypes with large primary porosity, and muddy spherulstones with large-scale matrix dissolution. Silicification and dolomitization are the main processes responsible for porosity reduction in both the *in situ* and the reworked lithotypes. Silicification is more expressive at the base of the unit, extensively replacing carbonate aggregates and particles, and filling all porosity as chalcedony and quartz cements. Dolomitization occurs dispersed, and is the main cement in redeposited and shrubstone samples. In the matrix-rich samples, it usually occurs both as matrix replacement and as late saddle dolomite cement in matrix dissolution pores. Correlation of geochemical logs and XRF analyses with petrographic data allowed the identification of patterns for intervals of "clean," matrix-free *in situ* and reworked lithotypes, mud-rich, silicified, and strongly dolomitized intervals. Though useful for defining general trends, the markedly high-frequency variations of pre-salt rocks due to the intercalation of *in situ* and reworked lithotypes and variable intensity in diagenetic processes, is below the detection ranges of the methodology. Bulk $^{86}Sr/^{87}Sr$ analysis of 54 -samples and LA-ICP-MS analysis on 21 thin sections indicate a largely homogenous, highly radiogenic composition (~0.1736) consistent with previous Pre-Salt data, with the reworked samples slightly more radiogenic and with higher SrO content. Bulk $\delta^{18}O$ and $\delta^{13}C$ values range from 0 to 5‰ and 2 to 4‰ respectively, suggesting an origin consistent with low temperature precipitation under highly evaporative conditions without significant organic contribution. This suggests a geochemically homogenous lacustrine system where the calcite aggregates formed from very similar abiotic processes.

Sedimentary succession with reddish multiphase infillings in the megalodontid bivalves and solution cavities in Julian Alps

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At a protected site in the Julian Alps (NW Slovenia), in the Pod Peski valley, red fillings of megalodontid bivalves occur in the Upper Triassic Dachstein limestone. Based on optical and cathodoluminescent microscopy and X-ray fluorescence (XRF) analysis, four generations of shell infillings were recognized, some of which contain both cement and sediment subgenerations. Recording and sampling of the limestone sequence a few meters below and above the "main" layer" containing the megalodontids mentioned above revealed that the limestone is characterized by solution cavities similar to the megalodontids. Namely, these cavities are also filled with reddish multigeneration sediment with alternating calcite cement. Adjacent neptunian dykes were studied to clarify their influence on the last generation fillings. Two of them, located directly on the "main" layer with red-filled megalodontids, contain planktonic foraminifera, indicating Middle Jurassic or younger age. The next two neptunian dykes are located directly above the "main" layer, and one contains clasts with calpionellis characteristic of the Late Jurassic/Early Cretaceous. The last dyke explored is located a few tens of meters from the "main" layer and is several hundred meters long. In a few sample from this dyke Early Cretaceous planktonic foraminifera were identified. Microscopic analysis revealed that the reddish sedimentary fillings are part of a complex paleokarst system that produced the first three generations of fillings, and in the last (fourth) generation we noted similarities between the megalodontid fillings and neptunian dykes on the "main" layer. In addition, a Santonian - Maastrichtian sedimentary fill with globotruncanid foraminifera was discovered in the upper part of the succession in one of the solution cavities.

Particle-shape control on grain distribution in calciturbidites: insights from experiments

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Particle transport and deposition in turbidity currents is governed by the balance between turbulent suspension and gravitational settling, with settling velocity becoming dominant during the final rain-out phases of decelerated turbidity currents on lobes. For turbidites of carbonate composition, existing models do not fully incorporate the complexity of the hydrodynamics of irregular skeletal grains. Differential particle settling velocities play a role in the sorting of grains in turbidity currents. There is a preference of grains with higher settling velocities to be deposited first, yielding a settling-velocity gradient in vertical and longitudinal cross sections through turbidite beds. If sediments contain little variation in particle shape and density, such as typical for siliciclastics, then settling velocity is dominantly controlled by grain size. Carbonate sediments, in contrast, are composed of non-skeletal and skeletal grains, complete specimens and/or fragments, with various growth structures, producing a wide distribution of particle shapes. Similar-sized skeletal carbonate grains may therefore settle at very different rates, while particles of different size may settle together. This work aims to constrain the extent to which shape-dependent differential settling velocities influence sorting mechanisms in carbonate turbidity currents. Experiments using natural skeletal sand were conducted to investigate the settling of carbonate grains in (i) isolation, (ii) vertically-settling suspensions, and (iii) turbidity currents. Size, density and shape parameters were analysed using high-resolution micro-CT. It was found that the effect of particle shape on the sorting mechanism operating in carbonate sediment suspensions becomes increasingly significant as grain size increases, in particular above medium sand. Carbonate turbidites may therefore be more poorly sorted than siliciclastic turbidites, which is expected to result in lower primary porosity in calciturbidites compared to siliciclastic turbidites.

Facies variability in carbonate turbidites in Ionian Basin outcrops (Cretaceous, Albania)

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Carbonate slope deposits form an important part of modern carbonate platform-slope-basin systems and ancient counterparts. Carbonate sediment sourced from platform margins, and remobilization of the slope itself, may accumulate in slope aprons or submarine fans, depending on the system morphology and the nature of the carbonate factories involved. This work investigates the deposits of unconfined carbonate sediment gravity flows derived from the margins of the southern province of the rudist-dominated Cretaceous Apulian carbonate platform. The studied deposits are part of the Ionian Basin succession that crops out today over ca. 25 km along strike, in a fold-and-thrust belt in southern Albania. The basal part of the succession (130 m, Campanian) comprises undeformed, sheet-like calciturbidites. This package is abruptly overlain by a series of five 10-50 meters thick mass transport deposits (MTDs) and intercalated calciturbidites (>200 m, Maastrichtian–Paleocene) that restore the MTD-inherited topography. Here, we focus on a 50 meter thick interval of the undeformed turbidite package, which is composed of grainy and muddy calciturbidites, hybrid beds, and occasional calcidebrites. Bed thickness ranges from a few centimetres to over three meters. Grains are principally of bioclastic origin and dominated by rudist fragments, but coarser grains include carbonate intraclasts. Deformed mud clasts are common, in particularly ‘floating’ in a muddy matrix. Complimentary thin sections facilitate the occasionally problematic discrimination between muddy turbidites and hemipelagic deposits rich in planktonic foraminifers. Three sedimentological logs of the same interval are presented at very high-resolution (sub-cm-scale) from three localities with several kilometres along-strike spacing from each other. Three marker beds are used for correlation between localities. The distribution of process-based facies is discussed using statistical methods to provide insight into the variation and predictability away from one-dimensional observations as for example encountered in exploration wells.

Bacterial communities in biofilms covering the active depositional surface of freshwater tufa

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In many modern freshwater carbonate settings, bacteria and EPS play significant roles in mineral precipitation, with contributions from algae, fungi, bryophytes, vascular plants and viruses, as well as abiotic processes. Bacteria are particularly abundant in microbial mats where they interact with fungi and viruses and produce EPS which stabilize cells and protect them from physical stresses (e.g., changes in salinity, temperature, UV radiation, desiccation). Investigations illustrated here concentrate on the bacterial composition of biofilms involved in mineral precipitation in modern active freshwater tufa sites in the United Kingdom, Germany, Italy and Slovakia. The temperature of the water involved ranges from 8ºC to 15.8ºC with pH between 7.9 and 8.5. The chemical composition of the waters is chiefly a Ca-HCO_3 saturated system (except for the German tufa) with variations in major and minor element contents dependent on the sampling site. Metagenomic analyses reveal that the biofilms are composed chiefly of the same classes of bacteria, but with variations in their abundance. The classes Betaproteobacteria, Alphaproteobacteria and Gammaproteobacteria, are dominant in nearly all samples. Less abundant are Clostridia, Actinomycetia, Bacteroida and Epsilonproteobacteria. However, statistical analysis (PCA) reveals that the bacterial distribution is similar in samples from the United Kingdom and Italy (group I) and in Germany and Slovakia (group II). Such bacterial groupings may be related to differences in temperature and water chemistry. Of the dominant bacterial orders, cyanobacteria (e.g., Synechococcales, Chroococcales), which are well documented to induce biomineralization, are subordinate. At this stage of analysis, it is suggested that cyanobacteria, which are present in lower concentrations relative to other bacterial groups, have the much greater potential to precipitate calcium carbonate. In addition to cyanobacteria, precipitation of calcium carbonate is also related to EPS, viruses and de-gassing (abiotic precipitation).

Fitted fabric grainstones – A common product of subaerial exposure and vadose diagenesis

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Many carbonate grainstones have fitted fabrics that form in the vadose zone and are therefore evidence for subaerial exposure. These grainstones have flattened and concavo-convex grain contacts where the grains fit together somewhat like puzzle pieces and are commonly lined with early marine or meteoric cement. Examples of these fitted fabric grainstones have been identified in carbonates from the Archean to the Holocene and likely occur in shallow marine grainstones throughout the geologic record. The first to recognize fitted fabric grainstones was R. J. Dunham, who found them in the ancient and then found a modern example forming in beachrock in Mexico. He summarized his findings in an unpublished report for Shell Oil Company in 1969. Others who were familiar with Dunham's work have made the same interpretation over the years but it never became widely recognized. He called the process by which the fitted fabric grainstones form "vadose compaction" and many of the observations made here were originally made by Dunham.

Fitting occurs due to dissolution at grain contacts by meteoric or mixed marine-meteoric fluids. Over time that dissolution flattens the contacts and leads to fitting of the grains to each other like puzzle pieces. As the grains are dissolved and fitted to each other, gaps develop between the grains that are held open by pillars of undissolved material. In most cases, that gap is later filled by either marine or meteoric isopachous rim cement. In either case, the cements form at or near the surface and postdate the fitting of the grains which means that the fitting also must have occurred at or very near the surface. Intraclasts of cemented fitted fabric grainstone have been found in cross-bedded grainstones that are not fitted, providing unequivocal evidence of their surficial origin.

Fitted fabrics are very common – far more common than karst, caliche, meniscus cements or other evidence of subaerial exposure. In a relatively short time, more than 40 examples were found from every time period in the Phanerozoic up to the modern and all the way back to the Archean by doing a simple online search for carbonate grainstone thin section photographs. They can form in a beach or shoal crest environment or in any grainstones that have been subaerially exposed for an extended period. They are commonly found under sequence and cycle boundaries but may also form in the early transgressive parts of sequences as platforms are flooded and beach facies are deposited. In the literature, fitted fabric grainstones are typically either overlooked or interpreted to have formed due to burial compaction. Fitted fabric grainstones should have the early cement that postdates the fitting, and although they may be later subjected to further burial compaction, they commonly do not have pressure solution features. The purposes of this talk will be to establish criteria to recognize fitted fabrics and to discuss their origin, distribution and utility as an indicator of subaerial exposure.

Unravelling the mystery of ribbon rocks as response to palaeoclimatic change in a late Cambrian carbonate ramp from the Zagros Basin (Iran)

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Ribbon rocks are a particular type of sedimentary deposits characterized by alternating thin- to medium-bedded carbonates and shales/marlstones. Their origin is not fully understood, and ribbon rocks have been attributed to various processes, including tidal, storm and turbidity currents and differential diagenesis. It follows that these deposits have been referred to numerous sedimentary environments, ranging from shallow (supratidal/intertidal) to deep-water settings. During the late Cambrian, ribbon rocks were ubiquitous, representing a precious record for understanding the palaeoenvironmental, palaeogeographic, and palaeoclimatic conditions of this time interval. The Zagros Basin (SW Iran) is a key area for studying the late Cambrian ribbon rock units because of continuous and well-exposed sedimentary successions. This study aimed to provide a depositional framework for the ribbon rock in the Zagros area and contribute to the palaeogeographic and palaeoclimatic assessment of the north-eastern margin of Gondwana during the late Cambrian. Two key sections of the Zagros chain were studied through high-resolution facies and microfacies analyses. Both are characterized in the lower part by normally-graded bioclastic limestones with common hummocky cross-stratification that pass upwards to micritic limestone-shale couplets and nodular limestones, containing a high amount of detrital quartz. In this latter interval, there is a gradual reduction in the thickness of limestone beds and a corresponding increase in siliciclastic mud until carbonate layers completely disappear. According to facies and microfacies data, the late Cambrian ribbon unit deposited along a mixed carbonate-siliciclastic ramp, characterized by frequent storm events with the deposition of tempestite layers in the inner and middle ramp zones. The predominantly muddy lithology in the upper portion of the ribbon unit suggests deposition in a deeper water setting (outer ramp). Contemporaneously the siliciclastic fraction increased, causing the crisis and drowning of the carbonate factory. These results highlight an origin of the ribbon rocks as related to frequent storm events. These latter and the evidence of a progressive increase of siliciclastic supply may be interpreted as signals of significant changes in the late Cambrian climate. The transition from arid to humid conditions, increased continental weathering, reorganization of oceanic currents, and carbon cycle perturbations marked these palaeoclimatic changes, related to the palaeoenvironmental and palaeogeographic evolution of the north-eastern Gondwanan margin during this time interval.

Enhancing image log data of the Brazilian pre-salt using medical CT scans and deep learning

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Image logs are very important tools for the geological interpretation and analysis of boreholes. They can be used to identify lithology, detect fractures, among other features that can affect reservoir quality and flow of oil and gas. However, such tools have limitations regarding spatial resolution and effects of artifacts, such as washouts, breakouts, tool miscalibration or tool marks. In addition to image logs, other important source of information about the lithology of the borehole's core is the medical X-rays computed tomography (CT) scans. The main advantage of such scans is the high spatial resolution, normally in the sub millimetre scale, and they are not affected by the artifacts that prejudice the quality of image logs. However, as the image logs, CTs have their own artifacts, such as beam hardening and metal artifacts, and limitations like less than 100% rock being recovered during the drilling. To address these limitations from image logs, researchers started to use machine- and deep learning algorithms, which are capable of learning complex patterns present on the dataset and possibly reduce such limitations. There are many works that address super resolution tasks in geosciences, normally related to high resolution- and micro-CT scans, where the objective is to further improve details. However, the improvement of image logs using CT scans is an underexplored subject in the literature. In this work, we explore the combination of deep super resolution algorithms and the data present on CTs to enhance their spatial resolution and exploit the fact that CTs are not exposed to the image log artifacts causes to filter out regions of artifacts in image logs. The dataset is composed by image logs and core CT scans from 3 wells of the pre-salt region of Brazil. The workflow will be composed by two main models. The first model will filter out regions with artifacts by detecting data anomalies on the image log. These anomalies will be any divergence between the core CT data and the image log that can be interpreted as one of the aforementioned artifacts. The output of this model will be a map of regions that could be damaged and, therefore, will not be used for the second model. This second model will be a super resolution model that will receive this map of artifacts and improve the spatial resolution of areas with less than moderate damage. The expected result of this work is a workflow that can deliver clean and pre-interpreted image log profiles for as many image logs as desired. The impact of this work will be the reduction of interpretation and data cleaning costs, which can lead to a better efficiency of geologists and petrophysics in their works.

Sequence stratigraphic interpretation of aggrading shallow marine carbonate systems: insights from the upper Albian peritidal succession of the Apulia Carbonate Platform

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The present study analyses the stratal architecture of an about 17 m thick upper Albian shallow-water carbonate succession cropping out along the sea-cliff bordering the Giovinazzo town seafront (Apulia, Southern Italy). This succession consists of peritidal facies associations showing a well-developed cyclic organization resulting in the vertical stacking of elementary sequences whose thickness range from a few cm to about 1.5 m. Elementary sequence is here defined as the smallest depositional unit, where facies evolution indicates the smallest depictable cycle of relative sea-level change. As a rule, a single elementary sequence corresponds to a single bed. Furthermore, facies evolution through time displays deepening-shallowing facies trends of different orders, resulting in a hierarchical stacking of sequences. Three to five elementary sequences stack into a small-scale sequence, which generally displays a deepening then shallowing trend and exhibits the relatively shallowest facies at its boundary. Two to four small-scale sequences stack into a medium-scale sequence, which again displays a general deepening-shallowing trend of facies evolution and the relatively shallowest facies at its boundary. Typically, the elementary sequences are thinner around the small-scale and medium-scale sequence boundaries, which suggests reduced accommodation space. Conversely, thick elementary sequences imply higher accommodation space. The medium-scale sequences then group into large-scale sequences. No unique large-scale sequence boundary or maximum-flooding surface can be identified; a sequence-boundary zone, covering an interval of lowest accommodation, and a maximum-flooding zone with evidence for relatively deep or open-marine water are here recognized. The sequence- and cyclostratigraphic analysis relates elementary, small-scale and medium-scale sequences to Milankovitch orbital cycles with durations of 20, 100, and 400 kyr respectively. They can be then compared to fourth, fifth, and sixth order parasequences. Furthermore, large-scale sequence boundary and maximum flooding zones are here compared with third-order sequence boundary and maximum flooding surfaces even if their expression in the field does not correspond to surfaces but to sediment thicknesses.

Siliciclastic input on the Lower Cretaceous shallow-water facies of the Getic Carbonate Platform (Eastern Serbia)

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The Getic Carbonate Platform (GCP) was a hundred of kilometres, laterally extensive Upper Jurassic-Lower Cretaceous carbonate system on the Northern Tethys margin, cropping out in Romania, Serbia and Bulgaria. While the shallow-water deposits of the GCP were studied in detail in Romania and Bulgaria, sedimentological and biostratigraphic analyses in the Serbian sector are lacking, and regional correlations are missing. This study focuses on the lowermost Cretaceous GCP succession investigated through three stratigraphic logs (log A 200 m, log B 110 m, log C 70 m thick) near Dimitrovgrad (Southeastern Serbia). Petrographic analyses allowed distinguishing 13 facies (F1-F13).

Logs were correlated based on the common occurrence of 3-8 m thick beds of siliceous sponge spicules packstone with chert (facies F11), sharply overlying shallow-water platform facies. Log A (190 m below the F11 bed) consists of few dms to 2 m thick beds of F1 (peloidal packstone/grainstone to rudstone surrounding dm- to m-scale boundstone lenses with corals, calcareous sponges, among which stromatoporoids, siliceous sponges, rudists and *Bacinella*/*Lithocodium*), alternating with facies F2 (peloidal micrite-coated grains packstone/grainstone), up to 2 m thick F10a and F10b (coral and stromatoporoid clotted peloidal micrite boundstone) and 10 m thick interval of F5 peloidal foraminiferal wackestone/packstone in the upper part of the log. Log A facies association is indicative of open marine, moderate to low-energy environments, below wave base. The lateral lower part of log B (75 m below the F11 bed) consists of few dms to 1 m thick beds of facies F6-F10 (F6 peloidal-foraminiferal packstone with fenestrae and oncoids; F7 peloidal-oncoidal packstone-grainstone with fenestrae; F8 oncoidal packstone-rudstone; F9 sponge spicules packstone with fenestrae and oncoids; F10a and F10c: coral and *Bacinella* boundstone) indicative of low-energy, restricted platform interior from subtidal to intertidal. The lower part of log C (55 m below the F11 bed) shows dm-thick beds of facies F2-F4 (F2 peloidal-micrite coated grains packstone/grainstone; F3 peloidal-crinoidal packstone; F4 peloidal wackestone with bryozoans). Shallow-water facies in the three logs are sharply overlain by F11 siliceous sponge spicule packstone followed, in logs B (35 m) and C (10 m), by crinoidal-rich facies: F12 (reddish crinoidal packstone with benthic foraminifera, sparse glauconite and quartz grains) and F13 (peloidal-crinoidal packstone with sparse glauconite and quartz grains).

The facies change from shallow-water packstone/rudstone and boundstone to sponge spicule and crinoidal packstone is interpreted as reflecting a rapid deepening with temporary drowning of the carbonate platform, marked by the onset of siliciclastic input up to tens of metres thick in the adjacent basinal areas.

The Upper Cretaceous carbonate source rocks of the Western Desert, Egypt: the East Beni Suef Basin as a case study

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The Upper Cretaceous Abu Roash Formation represents the most prolific carbonate source rocks in the Western Desert of Egypt, which is divided into seven members (A through G) according to its clastic/carbonate ratios. In this work, we integrated a multi-disciplinary approach using seismic profiles, well logging data, organic geochemical analyses, Scanning Electron Microscope (SEM), Energy Dispersive X-ray Spectrometer (EDS), and X-ray diffraction (XRD) to comprehensively evaluate the carbonate source rocks in terms of facies analysis, source rock potential, tectono-stratigraphic evolution, and depositional environments. The available data are from the East Beni Suef Basin (EBSB), Egypt. Seismically, the Abu Roash "F" source rocks show uniform parallel configuration with moderate to high continuity and relatively high amplitude reflectors. This reflects well stacked interbeds deposited within alternative high and low energy conditions. The organic geochemical analysis indicates that the Abu Roash "F" source rock is the main effective source rock in EBSB with good to excellent source potential, oil-prone mainly type II kerogen of marine organofacies, and immature to marginal maturity levels.

The petrographic analysis shows that Abu Roash "F" source rock consists of argillaceous limestones with abundant planktonic foraminifera, local dolomitic wackstones, and residual hydrocarbon along the laminae planes in a micritized detrital clay matrix. Backscattered scanning electron micrographs of the thin sections showed foraminifera filled with clay minerals mainly kaolinite and illite, abundant pyrite in a clay matrix, and amorphous organic matter. The sediments are rich in glauconite, suggesting a continental shelf marine depositional environment and low sedimentation rates under reducing conditions during the post-rifting phase of the basin.

Results of this work were integrated into a regional basin modelling workflow to reconstruct the burial and thermal history of the basin and the maturity of the source rocks to define the kitchen area of the basin and the migration pathways of the potential hydrocarbon accumulations for exploration activities.

Biotic & abiotic carbonate pathways: a key to sink anthropic CO_2?

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Since the early 20th century, extensive research on carbonate rocks has elucidated their formation as a result of intricate interactions among physical, biotic, and abiotic chemical processes. In order to meet our commitments under the 2015 Paris agreements, we need to find massive CO_2 storage capacities. How could our O&G basin modelling open pathways for CCS? A compelling recent example is the extraordinary continental Aptian Pre-salt deposits found in the South Atlantic conjugate margins. These deposits serve as a remarkable demonstration of how these three processes can govern the precipitation and accumulation of immense volumes of carbonates. In this review, we will summarize a few key insights from these reservoirs, namely: (1) the influence of igneous rocks on Abiotic carbonate precipitation and their implications for chemical mass balance, and (2) the effects of high influxes of CO_2 on Biotic carbonate production. The purpose of this presentation is to showcase several ongoing projects undertaken by the carbonate specialists' team at TotalEnergies, focusing on CO_2 storage through biotic and abiotic processes. One project that will be emphasized involves carbonate mineralization in basalts. Recent studies have shown that when basalt undergoes alteration in the presence of acidic fluids, it can release sufficient amounts of calcium and magnesium to trigger extensive carbonate precipitation. This work aims to review this process, drawing insights from both published natural analogues and in-house research. The primary issues addressed in this study are as follows: (1) Can we adapt such natural processes to an industrial scale using seawater to dissolve CO_2? (2) What are the prerequisites in terms of igneous rock types and reservoir properties? (3) Why are carbonate specialists (together with igneous and structural specialists) crucial for these types of applications?

Micritization products: a micro-taphonomic sequence recording pre-burial bio-physical-chemical processes in shallow marine carbonates (Red Sea, Arabian Sea and Arabian Gulf)

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When Bathurst (1966) first defined the term micritization, he could not fully describe the internal structure of the micritic envelopes he was observing: " *The vacated tube [e.g., microboring] is filled with micritic aragonite. This may consist of bunches of radiating needles…".* This led him to interpret the micritic envelopes as a single diagenetic feature. However, nowadays, the routine use of Scanning Electron Microscope (SEM) in petrography studies allows for describing in detail the internal heterogeneities of micritic envelopes. And by doing so, their interpretations can be appreciated as a micro-taphonomic tool recording bio-physical-chemical processes occurring in different environments before the onset of further diagenesis and the development of potential microporosity.
By coupling fieldwork, optical microscopy, and SEM images of unconsolidated carbonate sediments, the present study aims to characterize the micritization products in different shallow marine environments around the Arabian Plate (e.g., *sandy and ooid shoals, tidal flat and channel, mangroves forest, grass flat, inner lagoon, microbial mat;* Arabian Gulf, Arabian Sea, and Red Sea). Briefly, we show that the micritization processes are extreme on the western (Taruq Bay; KSA) and the south-eastern (Abu Dhabi Lagoon; UAE) shores of the Arabian Gulf. In these areas, the micritization mainly occurs in the subtidal / lower intertidal, moderate energy environments (e.g., *tidal flats/channels, sandy shoals)* following a specific pattern involving endolithic activity and concurrent cementation. On the other hand, the sandy sediments collected in low energy zones (e.g., *mangroves, grass flats*) do not show *in-situ* micritization, even if grains are strongly microbored with complex micritic envelopes. Then, in contrast to the Arabian Gulf, our comparative study shows that the area investigated along the Red Sea coast (Rabigh lagoon; KSA) only exhibits an intermediary degree of micritization. And, regarding the Arabian Sea, the sediment collected in the lagoon of Bar Al Hikman (Oman) is

not micritized, although also here, microborings are very common. Finally, from a conceptual point of view, we argue that describing micritic envelopes as a single diagenetic event using a single genetic model is an oversimplification that hides the complexity of microbial activity in reshaping carbonate grains and original sedimentary fabrics. High-resolution petrographical observations and a paradigm shift toward a parasequential approach to interpret micritization products appear crucial for recognizing depositional environments and the hydrodynamic conditions leading to carbonate deposition in tropical shallow marine settings.

Burrowed carbonates generating a dual porosity system: A multidisciplinary study from the Cenomanian–Turonian platform carbonates of the southern Apennines (Italy)

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Bioturbated carbonate sequences represent a challenge for reservoir characterization for both hydrocarbons depletion and CO_2 and Hydrogen storage. Data from bioturbated carbonate deposits across the world and from different stratigraphic intervals show that bioturbation strongly impact petrophysical properties, creating sedimentary heterogeneities and often enhancing poro/perm properties. In this work, a detailed study of a thick (75 m) Late Cenomanian-Early Turonian bioturbated carbonate succession from the Apennine Carbonate Platform (Southern Italy) has been performed. A multidisciplinary approach has been applied integrating facies, ichnological and petrophysical analyses using non-invasive techniques, such as Computed Tomography scanning (CT, MicroCT), and Nuclear Magnetic Resonance (NMR). The aim was to investigate and characterize the abundance of burrows, their connections, and describe the pore size distribution. Furthermore, geochemical, mineralogical, and petrographic analyses were integrated to understand the correlation between bioturbation, poro/perm characteristics and diagenetic processes. The studied sequence reveals a boxwork pattern of burrows organized with a preferential horizontal network with vertical shafts having Y- or T-shaped branching morphology in a firmground substrate. These evidences suggest the domination of *Thalassinoides* ichnotaxa. Eleven recognized lithofacies indicated a deepening upward trend that was accompanied by an increase of the number of *Thalassinoides* traces and porosity. The burrow conduits, as revealed by CT images, show low tortuosity with preferential vertical and oblique straight paths with circular to elliptical cross-sections. In the most burrowed intervals, the volume occupied is around 39% of the total rock. The burrows are generally filled with dolomite and have a porosity substantially higher than the muddy matrix. The isotopic signatures of C and O of fillings are different from that of the matrix. Pore Size Distribution estimated via Hg-porosimetry coupled with NMR, evidence that pore sizes are larger in the more dolomitized samples whereas the smallest pores are found in the calcitic matrix. Micro CT images allowed us to visualize in detail the pore sizes and the pore network in the traces and in the matrix and to model fluid flow through it. The multidisciplinary dataset we will present highlight the relevance of the combination of several methodologies to characterize heterogeneous carbonates to predict fluid flow, fluid-rocks interaction and diagenetic evolution. Understanding these processes is fundamental for any subsurface storage project.

On the mixed nature of carbonate systems: examples from the Murge Region (Plio-Pleistocene, southern Italy)

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The Murge region (Apulia Foreland, southern Italy) consists of an articulated system of horsts and grabens recording the remnants of an archipelago drowned during the Late Pliocene and Early Pleistocene, when a long-term subsidence-induced relative sea-level rise affected the area. Deposits of the Plio-Pleistocene "Calcarenite di Gravina" Fm record this phase of long-term transgression and comprise coarse-grained shallow-marine carbonates unconformably lying onto abraded Cretaceous limestones. The same formation is diachronously sealed by hemipelagic clays of the "argille subappennine" Fm through a drowning unconformity. In places, the "Calcarenite di Gravina" Fm exhibits a mixed composition, deriving from a combination of carbonate lithoclasts (extraclasts, i.e., terrigenous/epiclastic carbonate component) and bioclasts (intrabacinal carbonate component). Carbonate lithoclasts occur as either (i) minor components of mixed deposits or (ii) the main components of terrigenous facies or bodies. Carbonate lithoclasts are represented by rounded coarse-grained fragments (ranging from granules to pebbles in size) of Cretaceous limestones. Bioclasts belong to benthic and rare planktonic foraminifera associated with whole or fragmented skeletal grains of bivalves, echinoids, red algae, serpulids, barnacles, brachiopods, gastropods, and bryozoans.
Some examples of these carbonate mixed deposits (a gravelly beach, a delta, offshore clinobeds) will be shown.

Bedrock-constrained cool-water carbonate systems: examples from the Plio-Pleistocene of Apulia, southern Italy

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During the late Pliocene and early Pleistocene, the subsiding Apulia Foreland (southern Italy), made up of faulted Cretaceous to Miocene carbonate rocks, became a wide slow drowning archipelago. Because of this long-term relative sea-level rise, coarse-grained, bioclastic and locally biolithoclastic cool-water carbonate systems developed. The inherited faulted bedrock exerted the main control on the development of depositional systems, which were variable both along strike/dip and over time according to the wide spectrum of physiographic conditions met by the carbonate factories during a subsidence-induced transgression.

In such a context, carbonate sedimentation developed in several bedrock-constrained settings: (i) in shallow-sea basins (grabens) separated by exposed morpho-structural highs; (ii) on drowned morpho-structural highs (horsts), i.e. when flat top of submerged islands became sea-banks; (iii) on variably inclined sloping sides of islands; (iv) on steep slopes flanking flat shallow marine areas.

All these features were controlled by the vertical fault displacement (from a few metres up to about 100 m) and by the horizontal spacing of block-bounding faults affecting the bedrock. Highly-spaced faults with a relatively small displacement led to the development of homoclinal ramps, with bioclastic sedimentation. Closely-spaced faults led to the development of relatively steeper ramps, where along-dip sigmoidal bodies composed of either bioclastic or mixed bio-lithoclastic carbonate sediments were laid down. Highly-spaced faults with few tens of metres displacements formed a step-like morphology associated with either bypassed cliffs, or coarse-grained deltas made up of carbonate extraclasts, or either bioclastic base-of-slope aprons or fan-shaped bodies if fed by a shallower carbonate factory. The internal architecture of some of these carbonates will be shown.

Oolites as proxies for palaeoenvironmental reconstruction: Post-end-Triassic Mass Extinction oolites from Wadi Milaha, Musandam Peninsula, United Arab Emirates

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The ETME (end-Triassic Mass Extinction) is characterized by an atypically high deposition of ooids, as happened in the direct aftermath of other extinction events (e.g., Silurian and End-Permian). The Aragonite Sea II- Calcite Sea II transition is also located around this time interval, and its timing is still uncertain. Global perturbations triggered by the emplacement of the Central Atlantic Magmatic Province (CAMP) probably caused the ETME. Ooids are a powerful tool to investigate the original physicochemical composition of the oceans where they formed, along the margins of carbonate platforms. Here we present morphological classification and geochemical signature for post-ETME ooids and other kinds of coated grains. They are part of a mid-Norian-Hettangian section from the Emirates. We traced different assemblages of post-extinction ooids and coated grains through time. The ooids show high variability in size, development and crystal arrangement of the cortex. We used a multi-technique approach combining optical microscopy, modal analysis, LA-ICP-MS, SEM imaging, elemental mapping with EDS and EBSD. Our dataset supports the transgressive trend of other Hettangian sections around the world, with specific features connected to the demise of their carbonate factory in consequence of the ETME. Low-Mg calcite is inferred as original mineralogy of the ooids/coated grains in a time interval previously defined as an Aragonite II Sea. This has major implication on the understanding of the carbonate saturation in the oceans just after the mass-extinction. Further geochemical results highlight the presence of dysoxic conditions in the marine water, an increase in soil erosion and upwelling of deeper water enriched in nutrients, associated to the key stratigraphical interval with the best developed and highly diverse ooids. The upwelling of nutrients-rich deeper water proves essential for the accretion of well-developed ooids.

Multiscale study of fracture pattern in different Jurassic carbonate successions

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Carbonate reservoirs represent potential CO_2 storage sites that can be deployed to contrast the continue increase of greenhouse gases in the atmosphere. This is mainly due to their high primary porosity and typical brittle rheological behavior prone to develop fracture systems, with variable intensity and complexity. At the same time, such characteristics, in particular primary porosity, can be influenced by different diagenetic processes, causing sometimes a drastic change of rock texture and petrophysical properties. Moreover, the presence of faults and fractures hampers porosity estimation, depending on the lithofacies. The complex interactions between porosity and fractures require a multiscale characterization.

One way to assess the potential of a reservoir is to study superficial field analogues by quantifying and defining the fracture systems in different lithofacies.

In this context, the Umbria-Marche Apennines represent a great area of study, due to the large facies and petrophysical variability (both vertical and horizontal) of the exposed Mesozoic carbonate successions, fractured during a complex, multiphase tectonic history.

In this study, a multiscale characterization has been performed, in order to obtain detailed information about the fracture systems (orientation and geometry) and to define the influence of fracturing on the different lithofacies at different scales.

At the outcrop scale, structural analysis of the fractures (orientation and geometry) along oriented scanlines has been performed. For larger outcrops, and/or where the use of scanlines was not possible due to difficult access, an acquisition using UAV (unmanned aerial vehicle) has been made, in order to create a VOM (virtual outcrop model). In this case, fractures have been mapped through the use of the generated 3D model within the environment of OpenPlot software, through manual picking for the individual fractures.

Rock samples have been collected, aimed to study the orientation and geometry of the fractures at smaller scales (hand specimens for the mesoscale, thin sections for the microscale) on the different lithofacies considered. The fracture attitude at mesoscale and microscale has been detected using the MatLab toolbox FracPaQ, in order to perform spatial fracture analysis in the different lithofacies observed. For each lithology, the structural data collected at different scales were integrated through the creation of Discrete Fracture Networks.

Preliminary results confirm that the relationship between fractures and lithofacies is typically scale-depending, therefore a multiscale characterization is needed in order to have a complete view on the fracture-facies-porosity interactions.

Impact of depositional controls and lake-evolution on microbialite systems (Yacoraite Fm., Salta Basin, Argentina)

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The discoveries of the Pre-salt carbonates in Brazil sparked a great interest on microbial systems in lake settings, inducing extensive research and promoting our understanding on these complex systems.

The Yacoraite Formation (Maastrichtian-Danian) is a mixed carbonate-siliciclastic microbialite-bearing lacustrine succession, deposited in the Salta rift basin (Argentina), and provides the perfect setting to investigate the controls on lacustrine microbialite systems. Deposition in the Yacoraite paleo-lake represents a predominantly shallow-water ramp-like lake system, characterized by extensive wave-dominated oolitic shoals and bars parallel to lake margins, which provided a sheltered environment that allowed prolific stromatolite development. The stromatolites of the Yacoraite Formation form highly continuous levels extending for several hundreds of meters to kilometres, and are characterized by a limited number of morphologies at the macro-scale, namely microbial crusts, isolated domes, coalescent domes and tabular forms. Observations at the meso-scale, from hand samples and slabs, indicate more complex and diverse morphologies, with well laminated fabrics being common. Fabrics can be flat, wavy, micro-columnar and with convex morphologies, and are frequently intercalated with sediments such as bioclastic-oolitic grainstones. Stromatolite micro-fabrics show a high degree of complexity but can be classified in two main types: fine-grained fabrics and hybrid fabrics. Fine-grained fabrics present prevalently discontinuous and irregular laminations, and consist of micritic fine-agglutinated fabrics, clotted peloidal and filamentous fabrics. Hybrid fabrics on the other hand are more continuous and well laminated and show alternances between micritic laminae and sparitic crusts and fans, with spherulites and shrub-like fabrics being frequently observed. Stromatolites developed in the littoral areas of the Yacoraite paleo-lake, under shallow-water and moderate to low energy conditions.

The Yacoraite paleo-lake evolved from a relatively stable and perennial lake system (lake stage 1) into a rapidly fluctuating ephemeral lake system (stage 2), as a result of progressively changing environmental and climatic conditions toward more arid settings. Lake stage 1 (perennial) is characterized by widespread microbialite developments, with a high number of stromatolites (73% of all stromatolite levels) and high diversity in their morphology at the macro- and meso-scales, suggesting stable conditions with moderate to high salinity and limited siliciclastic input where microbial communities could thrive. Lake stage 2 (ephemeral) is characterized by highly fluctuating lake-level conditions and extreme salinities and subjected to frequent and repeated subaerial exposure phases. In this lake stage, stromatolites are scarce (27% of stromatolite levels), and the morphologies essentially represented only by coalescent domes. Furthermore, stromatolite fabrics at the meso- and micro-scale do not show any

particular trend or distribution throughout the whole Yacoraite Formation, possibly suggesting that these fabrics are not directly linked to specific depositional environments. Thus, the interpretation of lake conditions and stromatolite development cannot rely exclusively on these micro-fabrics.

Coupled silica and carbon cycles in hypersaline environments, possible influence of bacteriophage processes on mineralization and reservoir quality

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Microbial mats are biologically complex and have been considered to be important but basic ecosystems, which are related to the development of the biosphere conditions on Earth through geological time. They can be found globally in a wide range of environments, but most specifically they are abundant in hypersaline conditions, including in sabkha environments. In this study, we report an important diagenetic process related with silica and carbon cycles, which can occur in modern hypersaline environments. Significantly, these sabkha sediments can develop into potentially very important oil and gas reservoirs.

The processes of bio-mineral precipitation, as the result of interactions between biological activity and the environment, is often referred to as being *biologically-induced and controlled* mineralization. In contrast, *biologically-influenced* is related to extracellular polymeric substances (EPS) because this organic matrix provides physical protection and electrostatic interaction enabling specific ions accumulate. For example, sulphate reduction metabolisms can result in the incorporation of Mg^{2+} ions into the mineral lattice. However, the biological formation of Mg-carbonates and Mg-clays can ultimately influence the petrophysical properties of the host rock. For example, the transformation of Mg-carbonates into Mg-clays is an ongoing process in modern environments, as well as in the geological record. Indeed, newly observed biological processes involving the mineralization of carbonate and clay minerals have been associated with viruses (bacteriophage), which can, in turn, have an influence on organic mineralization. Thus, hypersaline environments, such as modern sabkhas, can provide an excellent template to test important implications of viruses for the global biogeochemical cycles, which are coupled with the silica and carbon cycles.

Three-dimensional seismic facies distribution and morphometric analysis of the Aptian Pre-salt Barra Velha Formation in Santos Basin, Brazil

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The high porosity and permeability facies of the lacustrine carbonate deposits of the Barra Velha Formation characterize some of the most productive accumulation in the pre-salt section of the Santos Basin. Reservoir models often overlook detailed three-dimensional architecture and distribution of these facies due to the limited characterization of subsurface data. Therefore, due to this carbonate reservoir's missing outcrop and modern analogues, developing field strategies based on quantitative data and geological concepts from seismic and well data is essential for accurate static and dynamic reservoir modelling. This study performs a detailed characterization of the seismic facies of the Barra Velha Formation based on morphometry measurements along with well correlation from a field in the Santos Basin. We identify and map five seismic facies: Clinoform (SFC), Mound (SFM), Structural High (SFH), Wedge (SFW), and Parallel (SFP), separated by three tectonic zones (western slope, basement, and eastern slope). The two types of clinoform (SC1 and SC2) are analysed, varying the slope angle from 6° to 9° and extending from hundreds of meters to a few kilometres. The spatial correlation between clustering tendencies and the tectonic setting over the area allows for identifying the two members of SFM highly related to faults (SM1 and SM2). The SM1 shows bidirectional seismic reflectors with dimensions of hundreds of meters on the western slope. It appears as continuous high-amplitude slightly-truncated reflectors; meanwhile, close to the main structural high, it shows chaotic low-amplitude seismic reflectors. The SM2 is described by an upward-concave shape with tens of meters in extension on the eastern slope, clustering on an echelon structure with a preferential orientation towards the northwest. Most SFM features seem to be connected via flank by the SFC and other seismic facies with significantly different seismic characteristics. The SFH varies along the azimuth of the main half-graben structure. We described four members (SFH1, SH2, SH3, and SH4) based on the interaction among the basement, the salt diapirs, and the surrounding termination of the seismic reflector close to the top of the reservoir. The SFW is described at the low regions by convex low-amplitude shapes truncating toward the top, providing insight into tectonism during depositional timing, independent from the upper reservoir depositional phase. The spatial correlation between the distribution of this seismic facies' architecture, the mineralogical fraction composition, and the

porosity logs may provide insight into the reservoir quality distribution. This result underlines the extreme heterogeneity of depositional and post-depositional configuration of the Aptian lacustrine carbonates and the relationship that may exist between tectonic and erosive processes to generate the final distribution of these reservoirs.

Sedimentology and C-O isotopic geochemistry of the Oligocene lacustrine carbonate, with implications of paleoclimate record in northern Tibet Plateau

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The Qaidam Basin in the northern Tibet Plateau is subjected to the influences of intersecting climatic systems (e.g., south/north airflow, monsoon, cold/warm and dry/wet air) of western China, which is sensitive to the Central Asia climate changes. The Qaidam Basin was brackish to saline lake during the Cenozoic time and characterized by dolomite and limestone mixed with black shale and siltstone.

The study area is in the Nanyishan, southwest of the Qaidam Basin. The lacustrine carbonates of the Oligocene (Upper XiaGanchaigou Formation) can be divided into 6 facies: Banded dolostone Facies consisting of light gray to white, 0.5 to 5 cm thick layers; Laminated dolostone Facies, less than 0.5 cm thick dolomite interbedded with the lamella black shale or gypsum layers; Algal dolostone Facies, 2 to 20 cm thick and rich in organic matters; Spatulate dolostones (dolomite breccia with elongated fragments) facies, 5 to 10 cm thick; Argillaceous (calcitic) dolomite facies and Straticulate limestone facies. In addition, the gypsum, pyrite, halite, mirabilite and celestite were identified in the sediments.

The lacustrine carbonates (especially dolomite), and their geochemistry and sedimentary environments contain much information on palaeoenvironment and palaeoclimate signatures. The $\delta^{18}O$ values (PDB) in the dolomitic or calcitic mudstone and limestone is ranging from -6.33 to -9.58‰. The apparent positive $\delta^{18}O$ values in the dolomites (0.7 to -4.58‰) suggest a stronger evaporation environment. The $\delta^{13}C$ values display a negative shift to positive shift from the beginning of the Oligocene to the Middle to the Late Oligocene (-0.22 to -4.14 to 0.48‰), which may reflect the progress of climate aridification, resulting from the uplift of the Tibetan Plateau, which could help us to reconstruct palaeoenvironmental and palaeoclimatic evolutions in western China and even Central Asia during Oligocene.

Spatial self-organization in carbonate depositional environments: process, product, environment, and implication

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Spatial self-organization (SSO) is a pervasive process in many modern natural systems, in which ordered and predictable pattern emerges through spatial interaction of system components. Despite many contemporary examples in ecology and geology, the potential role of SSO in carbonate depositional environment has largely been overlooked, which limits our ability to link the observed 'products' back to earth surface process, make other possible interpretations and understand the full implications for paleoenvironment and the potential long-term risk in the future. To fill this gap, we present two case studies from modern microbial carbonates, coral reefs, and one from the rock record considering peritidal cyclicity, integrating remote sensing imagery, pattern quantification, and numerical modelling. Microbialites can form elongated ridges in response to hydrodynamics and sedimentation. Reefs can coalesce and develop highly cellular reticulated morphology after reaching the sea level. Such cellular nature has profound effects on sea surface temperature and water turbidity, which may act as a feedback in this biologically self-organized system. By quantifying coral reef morphology from 60 sites on a global transect and using a process-based numerical model, we can simulate reef morphogenesis very similar to those which we have mapped in the real world from satellite both visually and statistically. Looking back in geological time, autogenic island progradation can produce cyclic strata, where subtidal carbonate factory width determines the sediment production and supply to the adjacent island, which in turn determines the island progradation rate and the resulting autocycle thickness. Despite many differences in the depositional process, environment and pattern details, coherent patterns can emerge in all three cases due to only internal interaction and without any pre-existing template (e.g., substrate topography) or external forcing, supporting the SSO hypothesis. With continued cross-disciplinary effort, we are moving one important step forward to prove SSO as an established fact in carbonate depositional environment and identify key controls on pattern formation.

Application of "double interface method"-"impression method" in the restoration of pre-sedimentary paleogeomorphology

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Marine carbonate oil and gas fields have become not only an important direction of oil and gas exploration in China and even the world, but also an important part of global oil and gas. The paleogeomorphology is affected by the regional tectonic location, climate, base level change and tectonic movement. Paleogeomorphology is a main factor that controls the development and distribution of sedimentary facies in the later stage of carbonate basins, and controls the reservoir-cap assemblage of late oil and gas reservoirs to some extent. Under the influence of Caledonian movement, the Ordovician Majiagou formation in Ordos basin uplifted on a large scale, forming undulating paleo-topography. Based on this, this paper combines "double interface method" and "impression method" to restore the paleogeomorphology and palaeostructure of the target layer in the study area. In-depth understanding of the paleogeomorphology and the development characteristics of late sedimentary facies in the study area and their relationship to the late reservoir control.