BOOK OF ABSTRACTS

1st SaltAges Conference

31.03.-04.04.2025, Kraków, Poland

CRACOW
SALTWORKS MUSEUM
IN WIELICZKA

Funded by
the European Union

Venue:

AGH University of Kraków

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30-059 Kraków

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Foreword

Dear Participants,

It is our great pleasure to welcome you to Kraków for the first in-person meeting of the COST Action **SaltAges** in Kraków. **SaltAges** is a collaborative and interdisciplinary network of researchers and innovators from Europe and beyond. This initiative unites experts from diverse fields to advance our understanding of salt giants—massive evaporitic deposits that hold critical clues to Earth's past environments, climate evolution, and geohazards.

The **SaltAges** network is dedicated to addressing key scientific questions related to salt giants, including:

- assessing the consequences of salt giant formation on biota, biogeochemical cycles, global and regional climate and ocean circulation;
- investigating the interaction between salt giants, climate and plate tectonics;
- clarifying the relationship between local and regional tectonics and marine gateway restriction;
- reviewing the role of evaporites in the evolution of human civilization; and
- identifying the importance, environmental effects and geohazards associated with their exploitation.

The aim of this conference is to foster collaboration among scientists working on salt giants worldwide, identifying key archetypes, reviewing the latest scientific methods for studying these formations, and discussing the challenges and opportunities linked to their exploration and utilization.

Over the course of five days, from **March 31st to April 4th, 2025**, participants will engage in stimulating **scientific sessions and discussions** (March 31st–April 2nd), followed by **two field excursions** (April 3rd–4th) to the salt-related geological sites in Poland: the **Wieliczka Salt Mine** and the **Ponidzie region**, located at the northern rim of the Carpathian foreland basin.

We look forward to insightful discussions, new collaborations, and a deeper understanding of the role salt giants play in Earth’s history and modern society.

Welcome to the conference, welcome to Kraków!

Conference programme

Monday, March 31st

Introduction		
09:00-09:30	Welcoming *(Piotr Krzywiec, Krzysztof Bukowski, Marta Adamuszek)*	
09:30-10:00	Introduction to SaltAges scope and plan (*Konstantina Agiadi)*	
Session 1. Climatic and biological impacts of marine gateway reconfigurations		
10:00-10:15	Introduction to WG1 (*Iuliana Vasiliev, Francesca Bulian, Darja Dankina)*	
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10:45-11:00	Introducing a water activity coefficient to account for abundance and isotopic compositions of the Mediterranean's Messinian gypsum and halite (*Fadl Raad)*	11
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11:15-11:30	Formation and Sequence Stratigraphy of the Zechstein Basin: Impacts on Biota (*Darja Dankina)*	12
11:30-11:45	Before, during, and after: Anatolian fossil fauna dynamics across the Messinian salinity crisis (*Serdar Mayda)*	13
11:45-12:00	Sr isotopes and organic geochemical results for a new evaporite record from the South Aegean (Exp IODP-398): insights into the environmental evolution of the Aegean during the Messinian Salinity Crisis (*Caroline Aparecida Pereira Dias)*	15
12:00-12:15	Unravel paleoenvironmental dynamics: multivariate analysis of biomarker data across the Messinian-Zanclean transition (*Franscesco Pilade)*	16
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14:00-14:15	Challenges in the salinity reconstructions of restricted marine basins (*Iuliana Vasiliev)*	18
14:15-14:30	Gateway induced Early Miocene (~20 Ma) anoxia in the Central Mediterranean (*Ray Zammit)*	19
14:30-14:45	Influence on surface ocean density on plankton biomineralization (*Stergios Zarkogiannis)*	20
14:45-15:00	The impact of the Messinian Salinity Crisis on Conidae (Gastropoda): Biogeographic isolation and faunal turnover (*Christos Psarras)*	21
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15:15-15:45	Discussion	
15:45-16:15	**STSM tool** (*Rachel Flecker)*	

16:15-16:30	Coffee break	
16:30-17:30	**Evaporite database** (*Eloi Gonzalez-Esvertit)*	
17:30-19:30	**Icebreaker and posters**	

Tuesday, April 1st

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10:00-10:15	Late Miocene-Quaternary reactivation of a Salt Nappe in the Algarve Basin (SW Iberian Margin): Geohazard and Energy Storage Implications (*Debora Pascoal Duarte)*	26
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11:00-11:15	Coffee break	
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NOTE:

All conference participants must adhere to the COST Action CA23124 SaltAges Code of Conduct: https://sites.google.com/view/saltages/home/code-of-conduct

Planktic and benthic foraminifers of the Alboran Basin: a record of environmental change before, during, and after the Messinian salinity crisis

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ABSTRACT

During the last 640 kyr of the Messinian stage (7.245–5.333 Ma), known as the Messinian Salinity Crisis (MSC), the Mediterranean underwent profound paleogeographic and paleoenvironmental changes. Studying shifts in marine biota is crucial for understanding the timing and magnitude of these transformations, particularly in relation to the reorganization and modification of Mediterranean-Atlantic marine gateways.

In this study, we present new benthic and planktic foraminiferal data from IODP Site U1611 (Exp. 401), located in the western Alboran Basin. This micropaleontological record, spanning the MSC and the precessional cycles before and after the crisis, fills a critical gap in the Alboran Sea record, previously drilled at ODP Site 976. Unlike Site 976, which contains a hiatus between ~6.9 Ma and the base of the Pliocene, the record from Site U1611 seems to be continuous and apparently free from significant erosional phases.

By integrating data from Site U1611 (base of the hole between ~6.82 to 7.10 Ma) with the existing record from Site 976, we reconstruct a nearly complete stratigraphic sequence from the late Tortonian to the early Zanclean for the Alboran Basin. This continuous record provides valuable insights into the paleoceanographic and paleoenvironmental changes that affected the Mediterranean water column before, during, and after the MSC.

Late Miocene alkenones of Eastern Paratethys track the basin restriction

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ABSTRACT

Long chain alkenones (LCA; C35−C42) are biomarkers produced exclusively by some haptophyte algae, a common phytoplankton group. Due to their overall good preservation in sediments, LCA were used over time as paleothermometers and paleoenvironmental indicators. C37 is usually preferred due to the larger range of producers, but C38 and C39 are also abundant in fossil records, their concentrations and isotopic signatures being useful to determine the producers type, and further the type of environment they have populated in the past. Particularly important are restrictive basins, where isolation induces major changes in the biotic assemblages and the chemistry of the water column. Rapid changes in the environment are adding an additional factor stress, the increase in alkenone production being associated with challenging environmental conditions. Here we analyze the alkenone record from a section in the Eastern Paratethys (Panagia, Taman, Russia), spanning the interval between 12.7–7.6 Ma. Before ~9.6 Ma, alkenones are present extremely rare and in very low quantities. After this moment, alkenones are abundant in the record and almost continuous. We have detected and measured the isotopic signatures for C37:3, C37:2, C38:3 Eth, C38:3 Meth, C38:2 Eth, C38:2 Meth, C39:3, C39:2 LCA, their presence indicating multiple sources, likely a mixture of group II (C37, C38:Eth) and III (C37, C38, C39) types, specific to brackish, coastal/shallow marine and marine waters. The hydrogen isotopic values also show multiple producers. δ2H depleted values are dominant for C37–C38 during highly evaporitic intervals, while more depleted C39 values are present in the wetter intervals. δ13C values show a progressive increase in productivity from 9.6 to 7.6 Ma, indicating an increase in the basin eutrophication and sedimentary input, as a consequence of the paratethyan continentalization. The alkenone record of Panagia section tracks the progressive isolation of the Eastern Paratethys, adding to other acquired geochemical proxies and sedimentology data.

Introducing a water activity coefficient to account for abundance and isotopic compositions of the Mediterranean's Messinian gypsum and halite

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ABSTRACT

A simple box model is developed to access the astronomical-modulated exchange of ocean seawater with the Mediterranean during the Late Miocene salinity crisis. The model differs from previous ones by using a unidirectional portal as the method to get salinity to increase to saturation for gypsum and halite. Flow through the entry portal switches in direction as climate oscillates from arid to wet during each precession cycle. Novel to the calculations is the incorporation of a water activity coefficient that reduces the rate of evaporation as salinity increases. As a result, the accumulation rate of gypsum and halite declines with time. The sodium, sulfate, potassium and magnesium ions observed from fluid inclusions in gypsum and halite are replicated in the model. The reduction in input from the exterior ocean and eventual closure of the gateway conforms with the sedimentological and geochemical behavior of the gypsum deposits on margins and halite in salt mines and reflection profiles. By showing that rain and rivers supply eight times more water to the Mediterranean brine than seawater during the hypersaline stage of the Late Miocene salinity crisis, the calculations resolve the geochemical riddle of "low salinity gypsum". The sulfur isotopes in gypsum derive from ocean seawater and the oxygen and hydrogen isotopes in the gypsum hydration water from atmospheric precipitation.

Formation and Sequence Stratigraphy of the Zechstein Basin: Impacts on Biota

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ABSTRACT

The Zechstein Basin is a marine, partly evaporitic intracratonic basin formed when the Boreal Ocean broke in from the north, creating an almost enclosed sea. The Zechstein transgression, along with earlier marine ingressions during Rotliegend deposition, was driven by significant thermal subsidence and tectonic activity associated with the Greenland-Norwegian Sea rift. The flooding exerted a loading effect on the lithosphere, leading to further regional subsidence and the progressive overstepping of the Rotliegend Basin margins. The Zechstein Sea extended from England through northern Germany into Poland and southern Latvia. Subsequent carbonate and evaporite deposits are classified into evaporite cycles. In the Anglo-Dutch and North German basins, Z1–Z7 cyclotherms have been identified; in Poland, PZ1–PZ4; in Lithuania, only Z1–Z2; and in Latvia, only Z1.

The Zechstein sequence includes a wide range of terrestrial and marine fauna and flora. The marine biota of Cycle 1 is well-documented in terms of trace fossils and macrofossils, including ichnological remains in bioturbated carbonates, stromatolite reefs, and various accounts of the diverse reef fauna described from across the basin.

Fish are widespread and diverse in the marl slates and carbonate deposits, despite the heterogeneous, inhospitable, anoxic, and euxinic conditions during deposition. The majority of species were freshwater and likely lived in a thin freshwater layer at the surface of nearshore lagoons.

Both macro- and microfossil evidence of vegetation are largely restricted to the earliest Zechstein, with only rare reports from Cycle 2. Vegetation is believed to have thrived during and after the initial transgression but disappeared shortly after as environmental conditions became harsher.

Studies indicate a uniform palynoflora, suggesting that the vegetation was also consistent. Minor regional variations are likely attributed to chronostratigraphically significant vegetation developments, which may correspond to wetter-transgressive or drying-regressive phases of Zechstein cyclicity.

The variability in fauna and flora, along with their broad distribution within the sea, could possibly be explained by the influence of sea level rise/fall and paleoenvironmental conditions, which led to an increased taphonomic window.

Before, during, and after: Anatolian fossil fauna dynamics across the Messinian salinity crisis

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ABSTRACT

The Develi locality in Western Anatolia (Manisa, Turkey) presents a significant stratigraphic sequence spanning the Late Miocene (Messinian) to the earliest Pliocene (Zanclean). This interval encompasses the critical period of the Messinian Salinity Crisis (MSC), a major paleoceanographic event that profoundly impacted the Mediterranean region between 5.96 and 5.33 Ma. This study integrates paleontological and geological data from Develi to reconstruct the paleoenvironmental and faunal dynamics of the eastern Aegean region during this pivotal phase. The Develi fossil vertebrate collection represents not only the sole Messinian locality in Western Anatolia but also documents the earliest occurrences of several taxa, providing unique insights into faunal connections in the region before and during the MSC. The lower (Messinian) section at Develi yield a diverse large-mammal assemblage, including the earliest records of several species. Among them are the proboscidean Anancus lehmanni, the large bovid Parabos sp., and new carnivore forms (Chasmaporthetes nov. sp., Nyctereutes nov. sp., and Eucyon debonisi). Two giraffid forms are represented by Palaeotragus sp., including a large-sized form of Sivatherium. Additionally, this level preserves the youngest known record of the aardvark Orycteropus sp. This assemblage suggests an open habitat during the Messinian. However, consideration of regional geological data, including Late Tortonian to Messinian crustal contraction, renewed subsidence, and volcanism in the nearby Samos Basin, alongside evidence for drier conditions and ephemeral alluvial systems, indicates a more complex paleoenvironmental scenario. Furthermore, analysis of dietary preferences from various large mammals from contemporaneous sites suggests a predominance of browsing resources, challenging the traditional view of a widespread open savanna (Pikermian Biome) and instead supporting a dry woodland or forested environment. The Develi region during the Messinian was likely influenced by broader regional aridification trends associated with the MSC. However, it may have experienced less extreme aridity than areas further east, aligning with a proposed west-to-east aridity gradient. The presence of taxa with Asian affinities, notably the early occurrence of the oldest canids (Nyctereutes vov.sp., Eucyon sp. of the Eastern Mediterranean raccoon dog sp., highlights Develi's biogeographic significance. This suggests potential faunal exchange across the eastern Aegean, possibly facilitated by temporary land bridges formed during the MSC. The Develi assemblage is further notable for containing specimens morphologically and biometrically very similar to Eucyon debonisi, previously known only from the Messinian of Spain, and a gazelle closely resembling Gazella soriae, known from the Early Pliocene of Spain. This observation suggests potential faunal connections with the western Mediterranean as well, raising questions about the timing and mechanisms of these exchanges. The upper (Zanclean) section at Develi contain a rich micromammal assemblage, including Occitanomys debruijni, Apodemus sp., Pseudomeriones sp., and a Microtodon - Promimomys transitional form. This assemblage indicates a shift toward more humid conditions in the earliest Pliocene, following the Zanclean Megaflood and the termination of the MSC. This transition is consistent with regional geological evidence from neighboring basins (e.g., the Samos Basin), suggesting the onset of a more humid climate and the development of swampy,

shallow lacustrine freshwater systems in the Zanclean. However, the continued presence of Pseudomeriones suggests that some degree of aridity may have persisted in Develi's local environment. Fluctuations in salinity, as evidenced by the ostracod assemblages collected from the upper sections of Develi, suggest a dynamic depositional environment in the Early Pliocene, likely a slightly saline lake with fluctuating water levels and salinity. This interpretation aligns with the broader regional trend toward more humid conditions in the Zanclean but also underscores localized variability within the Eastern Aegean. The relatively low salinity of brackish waters during the early and middle Pliocene may be linked to increased precipitation rates.

Sr isotopes and organic geochemical results for a new evaporite record from the South Aegean (Exp IODP-398): insights into the environmental evolution of the Aegean during the Messinian Salinity Crisis

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ABSTRACT

The timing of freshwater input from the Black Sea to the Mediterranean Sea during the Messinian Salinity Crisis (MSC) and its role in driving environmental change during salt giant formation are still hotly debated. One reason for this ongoing controversy is that late Miocene sequences from the connecting Aegean Sea are rare, and evaporite-bearing successions in the North Aegean have been variously assigned to both the MSC and earlier time intervals. Recently however, IODP Expedition 398, unexpectedly recovered a 120 m thick anhydrite-bearing sequence at Site 398-U1591C, southwest of Santorini. Initial sedimentological evaluation of the sequence suggests that the anhydrite is mostly a replacement for primary gypsum, which precipitated in very shallow water conditions. Sr isotope and biomarker data suggest that the recovered succession is part of the MSC and probably spans the top of Stage 1 through to Stage 3 and is overlain by a complete record of the Miocene-Pliocene boundary. These new data also indicate fluctuating marine/terrestrial conditions in the South Aegean during the MSC providing new insights into the evolution of the connection between the Black Sea and Mediterranean and the influence of their contrasting environmental and faunal domains.

Unravel paleoenvironmental dynamics: multivariate analysis of biomarker data across the Messinian-Zanclean transition

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ABSTRACT

The Messinian-Zanclean transition (5.33 Ma) represents a pivotal yet debated episode of environmental transformation in the Mediterranean Basin, marking the shift from the supposedly brackish to lacustrine Lago-Mare phase of the latest stage of the Messinian to marine conditions in the Zanclean. This study employs advanced multivariate statistical tools, including cluster and redundancy analysis, to unravel the complexities of an extended lipid biomarker-based dataset from the Maccarone section, Northern Italy. By integrating these techniques, we identified critical environmental drivers. Among them are organic matter preservation, water column stratification, and terrestrial-marine interactions), describing a gradual transition beginning at 5.35 Ma. The multivariate approach revealed nuanced patterns, which would have been obscured when using traditional methods only. This new approach helps in resolving conflicting interpretations and is challenging the long-held notion of a singular catastrophic flooding event. These findings underscore the power of multivariate statistics as an indispensable tool for decoding intricate paleoenvironmental records and refining our understanding of multi parametric paleoenvironmental and paleoecological reconstructions.

The International Ocean Drilling Programme (IODP-cubed)

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ABSTRACT

The International Ocean Drilling Programme (IODP3, https://iodp3.org/) is an international marine research collaboration that explores Earth's history and dynamics using ocean-going research platforms to recover data recorded in seafloor sediments and rocks and to monitor subseafloor environments. It builds from the long-living series of programs DSDP, ODP and IODP.

IODP3 will implement drilling expeditions using Mission Specific Platforms or the drilling vessel Chikyu. In addition to drilling expeditions, IODP3 will implement, and co-fund, a new type of projects called Scientific Projects using Ocean Drilling Archives (SPARCs). These are projects managed similarly to drilling expeditions (with co-chief scientists and an international science team) where the data used to reach scientific objectives are extracted from existing core materials from DSDP, ODP and IODP expeditions, or existing data bases. IODP3 proposals (for drilling expeditions and SPARCs) contain hypothesis-driven science addressing the vision provided by the "2050 Science Framework" document, and involve collaborations between international researchers from the multiple geoscience disciplines. The submission of drilling proposals for Land-to-Sea transects in collaboration with the International scientific Continental Drilling Program (ICDP) is particularly welcome.

Challenges in the salinity reconstruction of restricted marine basins

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ABSTRACT

Restricted basins are part of the oceanic system that are affected mostly by global climate. At times, the interchange of the tectonics and climate, especially in the gateway vicinity, can take over and be expressed in unpredictable alterations of the water temperature and salinity conditions. Multiple proxies (e.g., foraminifera-based Mg/Ca, biomarkers-based TEX86 and UK37, clumped isotopes) are available for quantitatively assessing the water temperature, even in restricted marine basins, although cautious need to be exerted. Past salinity reconstruction is still one of the parameters that are particularly challenging to reconstruct, even in for the Open Ocean. The task becomes even more difficult in restricted basins. We will exemplify part of the challenges by combining sea surface temperature (TEX86, UK'37) and δ18Oforam data to quanti-fy salinity changes in the pre-MSC Mediterranean, focusing on the interval between 7.5 and 5.9 Ma. Even though δ18Oforam analysis of Mediterranean Messinian successions exists for some time it was only recently that such data were combined with SST for a paleosalinity reconstruc-tions during the Messinian. We provided the first SSS estimates, unexpectedly discovering that, before the onset of the MSC, the Eastern Mediterranean (Kalamaki section, Greece) was a basin with similar-to-present salinity of 39. In contrast, calculated SSS for the Mediterranean between 6.41 and 6.15 Ma, reached 48, much higher than anywhere in the present-day. Extreme salinity (up to 48) was calculated for earlier Messinian in the Eastern Mediterranean. Two distinct warm and hypersaline events (at 6.9–6.82 Ma and 6.72 Ma) resulted in stressful conditions for the marine fauna during periods of overall strong evaporation (6.9–6.7 Ma). We found that, at 6.72 Ma, an important step in the Mediterranean restriction may have resulted from shallowing of the Mediterranean gateways, which would have reduced the Mediterranean marine outflow. While our latest work provided sea surface estimates at different locations in the Mediterrane-an, no bottom water temperature nor salinity are yet accounted for. Within this SaltAges we seek partners to achieve a further goal. By pairing sea surface temperature – bottom water tem-perature at the same stratigraphic level we plan a direct evaluation of sea surface salinity – bottom water salinity contrast at specific points in time, focusing at the most dissimilar connec-tivity settings leading to highest salinity differences between surface and bottom. We will apply the methodology for the most contrasting scenarios of the Messinian Mediterranean centered around 7.0, 6.8, 6.6, 6.4 and 6.2 Ma. As a final target will focus on obtaining the vertical and lon-gitudinal water density gradient in the Mediterranean during the Messinian and identify turning points into the Mediterranean Outflow Water formation.

Gateway induced Early Miocene (~20 Ma) anoxia in the Central Mediterranean

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ABSTRACT

The Messinian Salinity Crisis at the end of the Miocene represents the culmination of a sequence of basin restriction events in the Mediterranean Sea. The earliest significant basin restriction episode is the Mesopotamian Seaway Restriction event-1(MSR-1) (19.05–20.35 Ma) during which oceanic flow from the Indian Ocean via the Mesopotamian Seaway was severely restricted. This led to shifting of surface oceanic flow from an E-W to a W-E direction through the neo-Mediterranean basin. Such a shift in the lang standing water flow at low latitudes influenced the hydrological cycle over North Africa via intensification of Atlantic circulation.

The Early Miocene (Aquitanian-Burdigalian) il-Blata section in Malta hosts evidence for a temporary perturbation in Mediterranean paleoenvironment associated with MSR-1. Such a perturbation was likely driven by rapid changes in the hydrological cycle in the region. The presence of authigenic Fe-dolomite together with gypsum infilling foraminiferal tests, framboidal pyrite and the general absence of planktic foraminifera is indicative of environmental stress brought about by enhanced continental runoff generating density stratified waters. The section also contains organic-rich horizons, with maximum total organic carbon (1.4 %) coinciding with peak in Fe-Dolomite abundances and maximum negative excursion in δ13C (bulk and Fe-dolomite). These deposits currently represent the oldest Mediterranean sapropelic layers (~18.8 Ma) and therefore suggest that basin restriction had an effect on sedimentation in the region much earlier than previously assumed.

The organic-rich horizons are topped by cream coloured chert-bearing siliceous layers, suggestive of a siliceous productivity bloom. This shift in paleoenvironment can be linked to rising global temperatures and associated increased sea-level. It can be reasonably assumed that the Mesopotamian Seaway was reopened via a eustatic control, shifting the Mediterranean surface currents back to an E-W flow and reoxygenating the water column.

Influence on surface ocean density on plankton biomineralization

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ABSTRACT

Planktonic foraminifera play a crucial role in global pelagic biogeochemistry, export fluxes, and seawater properties. As calcifying plankton, their mass significantly contributes to the biological carbon pump by ballasting particulate organic matter, while their calcification influences carbon cycling through both carbonate deposition and CO_2 production during $CaCO_3$ formation.

This study reveals that ocean density exerts a key control on foraminiferal biomineralization, suggesting that shell weights may serve as a seawater density proxy. Since foraminifera are non-motile, glacial-interglacial ocean density fluctuations could drive shell weight variations for buoyancy regulation, assuming foraminifera maintain consistent depth habitats. This newly described mechanism provides a novel perspective on marine carbon cycling and offers a potential tool for reconstructing past ocean circulation by identifying historical density gradients.

Additionally, findings show that foraminiferal calcification intensifies with depth, corresponding to increasing seawater density. This pattern enhances our understanding of how different ocean strata influence the carbon cycle and highlights the potential to decipher the density structure of the upper ocean based on foraminiferal calcification patterns.

The impact of the Messinian Salinity Crisis on Conidae (Gastropoda): Biogeographic isolation and faunal turnover

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ABSTRACT

Prior to the Messinian Salinity Crisis (MSC) (5.96 –5.33 million years ago), many subgenera of the marine gastropod family Conidae in the Mediterranean and Paratethys regions were allopatric species, isolated from their Indo-Pacific relatives due to the 'Gomphotherium Landbridge', which acted as a barrier to marine faunal exchange between the Indian Ocean and the Proto-Mediterranean Sea since approximately 20 million years ago. The MSC, a major paleoenvironmental event, drastically altered the Mediterranean ecosystem by restricting water exchange with the Atlantic, leading to the extinction of most marine species in the Basin. Following the MSC, the reopening of the Gibraltar Strait allowed recolonization by Atlantic species, resulting in a complete biogeographic shift in Conidae diversity. Notably, post-MSC Mediterranean Conidae species showed similarity only to those from the Atlantic, with several pre-MSC subgenera never reappearing in the region. One genus and four subgenera disappeared entirely, including Conus (Plagioconus) Tucker & Tenorio, 2009, which went extinct. Despite this turnover, Mediterranean Conidae remained diverse, with up to 22 species documented in Italy and Spain. However, data on Conidae diversity from the Pliocene of Greece remains insufficient. This study aims to analyse shifts in Conidae faunal composition, focusing on species diversity in the Early Pliocene of Greece, their paleobiogeographic distribution, and the causes behind their gradual decline over the last 8 million years.

Revised timing and evolution of the Messinian Salinity Crisis in the Mediterranean area

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ABSTRACT

In recent years, the debate on the evolution of the depositional patterns of evaporites during the Messinian Salinity Crisis has been rekindled with three opposing concepts. One theory is focused on the desiccation model, or strong sea-level drawdown, during the crisis culmination, with the return to normal marine conditions through a catastrophic flood at the base of the Zanclean. Another one states that the marine filling, partial or complete, would have occurred during the late Messinian. Finally, another theory states there was no strong sea-level drawdown. In order to have a comprehensive model of the phenomenon of the depositional patterns, that triggered the deposition of the evaporites, this study reconsiders several Messinian successions, located in different areas of the Mediterranean (Spain, Algeria, Sicily, Ionian Islands and ODP sites), analyzing the sequences from the microfossiliferous, petrographic and geochemical points of view.

The data show a salinity increasing with the progressive lowering of the sea level that caused upheavals in the marine biodiversity, up to the formation of salt deposits in different sub-basins. The gradual sea-level drop, due to the reduction of the connections between the Mediterranean and the Atlantic Ocean, caused the progressive isolation of marginal areas from deep basin, with the deposition of evaporites in shallow water basin and emerged and in deep areas followed by large fresh water influxes.

This mechanism, controlled by the contemporaneous sea level drawdown, Milankovitch cycles and tectonic uplift of the of the Sicilian-Maghrebian Apennine chain favoured the isolation of the Mediterranean basin from Atlantic Ocean with the lateral deposition of different types of evaporites in the various sub-basins and in deep areas. In many areas of Sicily the "Calcare di Base" and selenitic gypsum pass laterally to the Halite and Potassic Salts. These lithological units are covered in discordance by Lago-Mare sediments and truncated at the top by the marine Zanclean sediments.

Salt wall welding in the Moroccan High Atlas - smearing of clay and evaporites along fragmented igneous intrusions

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ABSTRACT

The High Atlas in Morocco represents an orogeny formed by the tectonic inversion of the Tethyan rift system. First, in the Early Jurassic, a Late Triassic salt accumulated above basement faults into salt pillows and walls. The salt walls were later intruded by abundant Upper Jurrasic gabbro intrusions forming shallow laccoliths and dykes possibly also feeding extrusive basaltic lava flows. Finally, these salt walls, the gabbro intrusions, and lava flows were squeezed during the Cenozoic tectonic convergence to form the extensive salt weld arrays. The salt walls/welds in the Atlas Mountains form a braided pattern that stretches from SE to NW over 2000 km from Morocco to Tunisia. Exposures of the Triassic evaporitic successions inside these structures consist of red Triassic clays surrounding the fragmented volcanic intrusions, patches of evaporites (gypsum), and lower Jurassic dolomite stringers. In our work, we analyzed the composition and internal structure of the two salt welds in High Atlas using field structural mapping to reconstruct the halokinetic processes and deformation related to salt welding in the final stages of the Cenozoic compression in the High Atlas. Our mapping focussed on the Tazoult salt wall and the Tafrout salt diapir in the central portion of this orogenic belt.

In the Tazoult salt wall, the distribution and fold patterns inside the dolomite stringers reflect the extent and the flow regime of the former salt sheet that encased these stringers: 1) along the walls of the salt wall/weld in contact to the adjacent host halokinetic sequences, the dolomite stringers reflect vertical shortening from kink-band and chevron fold patterns, 2) in the central portion of the Tazoult salt wall, the stringers display closed recumbent folds indicating the collapse of vertical layering in a laterally spreading channel, and 3) in the SE portion of the exposure, Z-shaped folds and kink-bands in flat-lying stringers indicate the lateral extrusion of salt in a salt sheet. Although the halite exposures are absent, outcrops of red Triassic clays display deformational layering inside the salt walls. These layered clays are either damp, soft, and moldable in hand, or form a solid mudrock interspersed by networks of gypsum and hematite-coated fractures. Domains of ductile deformation of the soft clay-rich breccia around several-meter large clasts of clast-supported breccia and volcanic rocks indicate large deformation of the clay-rich residues of the evaporite sequence during the salt-wall welding. At the Tafrout diapir, located 25 km ESE from the Tazoult salt wall, outcrops of a salt weld display tectonic breccia that contains angular fragments of the Triassic sedimentary rock fragments and volcanic rocks encased in folded clay layers and stretched along deformation fabric parallel to the salt weld. These observations suggest that the strength of salt welds along the Atlas Mountains is controlled most importantly by the rheology of Triassic clays modulated by fluids. A magnetotelluric mapping of the area was carried out to visualize the subsurface resistivity structure of the Tazoult salt wall, which may indicate the extent of conductive halite vs. resistive sediments (e.g. the Triassic clays) or igneous intrusions.

Salt-driven submarine landslides induce tsunami waves in hypersaline anoxic brine pools

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ABSTRACT

Subsea hypersaline anoxic brine pools are dynamic and extreme environments with significant geological and biological implications, offering valuable insights into potential life on other planets. Brine pools, such as the Orca Basin in the Gulf of Mexico, are traditionally considered stable, stratified systems. However, new findings reveal that these systems can be disrupted by massive, fast-moving submarine landslides, which generate tsunami-like waves with amplitudes reaching hundreds of meters. These brine waves can negatively impact biological communities and spread hypersaline brine into adjacent basins. The Orca Basin, shaped by salt-withdrawal processes, features several large escarpments that indicate active mass transport on its margins. Salt tectonics in this region is the primary driver of large submarine landslides into the basin. One such landslide, hypothesized to have occurred 7,900–8,500 years ago, likely coincided with or shortly followed the formation of the brine pool. This event produced a tsunami-like wave, destabilizing the pool and challenging its perceived stability. However, constraining the timing of submarine landslides remains a key challenge in understanding their impacts. In the Orca Basin, we applied a novel age-dating method that provides a generalized analytical solution for dating submarine slides, offering new tools to study these dynamic systems. By mapping an irregular bottom simulating reflection (BSR) beneath a submarine landslide using three-dimensional seismic data, we found that the gas hydrate stability zone (GHSZ) remains in transition, mimicking pre-slide seafloor geometry rather than modern bathymetry. Transient conductive heat-flow modeling indicates that the slope failure occurred approximately 8,000 years ago, shortly after the brine pool's formation. These findings underscore the intertwined roles of submarine landslides and brine pools in shaping seafloor environments. The study advances our understanding of extreme subsea systems, with implications for geophysical processes, ecosystem dynamics, and submarine geohazards.

Exploring the Subsurface Energy Storage Potential in Salt Structures in the Southern North Sea

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ABSTRACT

The Southern North Sea (SNS) has played a crucial role in the UK's oil and gas sector, undergoing decades of hydrocarbon exploration and production while significantly contributing to the country's energy mix. Although production levels have declined over me, the SNS remains a vital component of the UK's energy transition initiatives. A cornerstone in these policies involves a considerable increase in the development and deployment of renewable energy resources such as wind power, aiming for up to 50 GW of wind capacity by 2030. The variable nature of wind energy necessitates the development of large-scale energy storage solutions.

Among the various energy storage technologies, geological storage offers the scale required to meet future energy demands effectively. Salt caverns, formed through solution mining, have a long history of onshore natural gas storage and have the potential for large-scale power-to-gas energy storage.

The South Permian Basin (SPB), which includes the SNS, is characterised by thick accumulations of evaporite sequences, extensively deformed by post-Permian salt movement, resulting in abundant concordant and discordant salt structures. Although offshore salt caverns are still largely unexplored, integrating existing knowledge with offshore wind power projects and adjacent salt structures presents a significant opportunity for grid-scale subsurface energy storage.

In this study, we adapted the play fairway screening method to identify potential exploration targets on a regional scale. This approach considered the presence of offshore wind farms, the distribution of salt structures, and salt volumes within salt cavern operational depth limits, producing a common-risk-assessment map that highlights 36 potential exploration targets, with 17 located in the UK sector of the SNS.

The storage capacity of the identified structures in the UK sector ranges from 1.5 GWh to approximately 1 TWh, with an average of 134 GWh. Accounting for uncertain es, probabilistic metrics suggest that the average energy storage potential of these offshore salt structures has a 90% chance of being equal to or above 13 GWh, a 50% chance of being equal to or above 67 GWh, and a 10% chance of being equal to or above 121 GWh.

These findings indicate significant potential for developing offshore salt caverns for energy storage. However, many technical, geological, and environmental challenges remain. Thoroughly assessing these uncertainties is crucial to ascertaining the feasibility of establishing offshore salt cavern storage facilities.

Late Miocene-Quaternary reactivation of a Salt Nappe in the Algarve Basin (SW Iberian Margin): Geohazard and Energy Storage Implications

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ABSTRACT

The effect of salt tectonics on subsurface storage potential and geohazards remains a critical yet underexplored matter. Geologic energy storage and carbon capture and storage (CCS) are key for the energy transition process, relying on secure reservoirs. However, salt movement and related deformation can impact the reservoir integrity, induce faulting and thus create pathways for fluid migration, compromising storage efficiency.

The Esperança Salt Nappe, an allochthonous salt canopy in the eastern Algarve Basin (SW Iberian Margin), was emplaced from Middle Jurassic to Early Cretaceous, and consists of Triassic evaporites. Its reactivation deforms the Miocene-Quaternary overburden sequence, composed of turbiditic-hemipelagic and bottom-currents (contourite) deposits. Contourite deposits have recently gained interest for geological storage due to their alternating layers of permeable and porous coarse-grained sediments (potential reservoirs) and fine-grained sediment (behaving as seals). However, fluid migration pathways and seepage have been recognised in the basin, evidenced by: i) acoustic disturbance zones and enhanced reflectors are observed on top of salt structures, and ii) faults related to salt-deformation culminate in pockmarks observed at the seafloor.

Several geological processes such as sea-level changes, high sedimentation rates, tectonic deformation and earthquakes may trigger fluid migration and expulsion at the seafloor. The presence of seepage above an important salt deformed area suggests that halokinetic activity, combined with the factors mentioned above, plays a role in triggering fluid migration, and may even act as fluid sources. The risks associated with salt deformation, fault and fracture reactivation as well the potential for induced micro-seismicity, need to be carefully evaluated to ensure safe and secure energy storage on the Algarve Basin.

Through the analysis of regional seismic reflection data and a borehole-supported chronological framework, this study investigates the role of halokinetic deformation on deep-water sedimentation and fluid migration pathways. The findings aim to enhance risk assessment for energy storage and CCS by examining reservoir performance and long-term seal integrity in salt-related systems.

Developing an atlas of evaporite-related geomorphology as a foundation for geohazard assessment

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ABSTRACT

Evaporite bodies are known to lead to karst geomorphologies in onshore settings, due to the dissolution of evaporitic rocks in meteoric or undersaturated groundwater. Rates of dissolution in evaporites is much greater than that in carbonates (the other karst-forming lithology), meaning evaporite karst landforms can develop within a human lifetime, often causing severe disruptions to infrastructure.

In offshore settings, spatially varying sediment loading and compaction of overburden sediments mobilizes salt bodies—a process known as halokinesis or salt tectonics. This results in salt diapirism, allochthonous extrusion, downslope gliding, and other related salt motion. Salt tectonics operates at a rate slower than dissolution, but plays a critical role in shaping submarine geomorphology, contributing to slope instability and gravity-driven mass movements, which can impact seafloor infrastructure and even trigger tsunamis. Additionally, salt tectonics induces faulting, enhances fluid flow, and creates anomalous geopressure, posing serious geohazards during drilling operations.

In both onshore and offshore contexts, a key variable in the severity of evaporite-related geohazards is the rate of movement and geomorphological development. We therefore propose building an atlas of evaporite-related geomorphologies, both onshore and offshore, to improve our understanding on the differences between slow- and fast-rate evaporite geomorphological development. Ultimately, we hope such a tool can help in the assessment and mitigation of evaporite-related hazards.

Tuzla - a city on a "grain of salt", from the Neolithic to the present day

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ABSTRACT

The first written records of the existence of natural salt springs in Tuzla date back to the early Middle Ages, although it can be said with certainty that salt has been obtained in these areas since time immemorial.

Industrial exploitation of salt from the Tuzla deposits began in 1885, following the model of colonial industrialization in Bosnia and Herzegovina. The Tuzla salt deposit, although relatively small in size, has a long and problematic history of exploitation. Around 90 million m3 of salt water with an average salinity of 300 kg/m3 was extracted from the Tuzla deposit through uncontrolled leaching, i.e. around 27 million tons of salt were exploited, thus creating a solid mass deficit of around 12.6 million m3. In 1971, multi-year research was started. The principle of multidisciplinarity was implemented in the process of researching the Tetima rock salt deposits. Due to problems with the ground subsidence in the city center, the planned sinking of the Tušanj pit was started in 2002. During the planned sinking of the underground mine "Tušanj" into the empty space, approximately 1,200,000 m3 of salt water was deposited. The planned sinking, according to the approved project documentation, was completed in early January 2005.

The role of salt in the Central and Eastern Anatolian lifeways: crossroads of prehistoric and current times

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ABSTRACT

Anatolia, being the westernmost protrusion of Asia, has some of the biggest salt reserves in southwest Asia. Inhabited as early as the Paleolithic, the human and animal settlers of the region have been facilitating this mineral in the forms of rock salt, spring salt, and salt licks through millennia. Salt was exploited and traded for dietary uses, used for certain crafts, and had a significant function in the ritual world of Anatolian settlers for ages. This talk will focus on the long-term, multi-layered role of salt in Türkiye through synthesizing geological, archaeological, ethno(archaeological), and textual data. Data gathered from recent fieldwork in central and eastern Anatolia validate significant utilization of salt for subsistence economies. Salt is also valued for certain traditional and religious practices. Through deriving examples from prehistoric, protohistoric, and contemporary central and eastern Anatolia, this presentation aims to discuss the sustaining role of salt within the broader socioeconomic setting of the diverse geography of the study area.

How numerical modelling advances our understanding of the behaviour of salt-related systems

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ABSTRACT

Numerical modelling has become an essential tool for addressing a wide range of geological challenges, including those related to rock salt. Its key advantage lies in the ability to explore complex system behaviour under controlled conditions, allowing for the study of geological processes over vast timescales, far beyond the limitations of direct field observations and laboratory experiments. In the presentation, I would like to show case studies demonstrating how numerical modelling enhances our understanding of rock salt behaviour and salt-related systems. The examples span different scales of analysis and diverse applications. The first example examines folded structures observed at the outcrop scale in the Ocnele Salt Mine (Romania). These structures develop within the mechanically stratified rock salt, where stratification is attributed to variations in impurity content. The numerical modelling carried out in the study provided constrains on the dominant deformation mechanism active during the structure formation and enabled the estimation of the the effective viscosity ratio between pure and impure rock salt layers. Second example shows investigations motivated by seismic data observations of the Szubin salt pillow structure located within the Polish Basin, where we tested the hypothesis that the structure resulted from the inversion of an evaporite-filled half-graben. Our numerical modelling supported this hypothesis. Moreover, the systematic analysis of the various geometrical and mechanical parameters, provided deeper insight into the internal evaporite deformation and the factors controlling the final structure geometry. The third example demonstrates the application of numerical modelling to industrial challenges related to designing of the underground salt caverns. This study investigated the relationship between cavern convergence rates and shape under different scenarios of mechanical stratification within bedded evaporites, providing valuable constraints for the safe and efficient management of subsurface storage facilities. In summary, numerical modelling serves as a powerful tool for range of academic research and industrial challenges. It enhances our understanding of various geological processes and their key controlling parameters in a safe, efficient, and cost-effective manner. Ultimately, it provides a robust framework for testing hypotheses, supporting decision-making and mitigating geological risks in both natural and engineered environments.

Hybrid extensional-compressional origin of salt diapirs in intracontinental basin – Mesozoic evolution of the Goleniów salt structure, NW Poland

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ABSTRACT

Salt structures may play a significant role in energy transformation since salt constitutes solid host rock for the construction of underground energy storage. Caverns created within the salt mass can be also utilized as volumes for carbon capture and storage as well. Particularly important geological objects in this context in Poland are salt diapirs of the Zechstein Supergroup, occurring in a narrow zone within the Central and NW parts of the Polish Basin. Salt diapirs form basin-scale isolated structures with complex 3D geometry. The development of a reliable structural and genetic model of these structures is the key to the success of a future storage project. Presented in this paper interpretation of a good quality 2D seismic profiles measured above the Goleniów structure allowed for the evaluation of its spatial variability and revealed its complex growth during Mesozoic evolution of the Polish Basin.

The Goleniów structure consists of several tectonic segments, where deformation style varies considerably along the strike. Starting from NNW the following segments are observed: i) wide inverted graben, ii) salt wall, iii) detachment fold, iv) thrust-fold zone and v) inverted half graben where degree of inversion gradually decreases towards SSE.

The evolution of the diapir started in Late Triassic with regional extension that triggered formation of the peripheral fault zone with an asymmetric reactive diapir. The salt diapir continued its growth as a passive diapir after the Late Triassic-Early Jurassic breakthrough. Depletion of salt in the source layer was the main factor of its consecutive Late Jurassic burial. Further extension in Early Cretaceous caused the diapir to fall, which resulted in formation of the Lower Cretaceous depocenter observed above the crest along of the Goleniów structure. The Goleniów structure was substantially rebuilt during the Late Cretaceous inversion of the Polish Basin. In other segments of the Goleniów structure, a salt diapir did not develop and was replaced by salt-related structures detached within the Zechstein evaporates. Thin-skinned grabens and half-grabens formed during the Late Triassic-Early Jurassic extensional phase were compressionally re-shaped during the Late Cretaceous basin inversion

The final shape of the Goleniów structure after its reactivation is a result of its pre-inversion geometry, amount of salt and variable magnitude of shortening in its specific segments.

Recent breakthroughs in halite fluid inclusion analysis as new gateways to water chemical composition, volume, lake level and temperature

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ABSTRACT

Chemical composition, volume, lake level and temperature are crucial and, yet, elusive parameters of the waterbodies that generated salt giants. Here, we present new analytical methods using fluid inclusions in halite (Brillouin spectroscopy, Laser-ablation ICP mass spectrometry, Nucleation-assisted microthermometry), combined with chemical and limnological modelling, to reconstruct these parameters. We illustrate these methods with results from halites sampled in cores from the deepest floor of the Dead Sea, in the southern Levant, in the scope of the Marie Skłodowska-Curie CROSSROADS project. We find gradual and significant changes in the concentration of the major elements from the start to the end of the Holocene, all quantitatively in line with the evaporative shrinkage of a halite-saturated waterbody. Reconstructed lake levels match the elevation of dated fossil beaches. Along with reconstructed water temperatures, they suggest that climate became drier and cooler until the middle of the Holocene period and wetter and warmer afterwards. These results pave the way to a better understanding of the formation of salt giants and their environmental and climatic contexts.

Salt on Asteroid Bennu

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ABSTRACT

Salt and related evaporite minerals have been documented extensively on Earth, as well as on Mars, the dwarf planet Ceres, and the icy moons of Jupiter and Saturn. Despite their widespread occurrence, they are poorly understood outside Earth owing to a lack of samples available for study in laboratories on Earth. We report the occurrence of a variety of salt minerals in samples of the asteroid (101955)Bennu returned by the OSIRIS-REx mission. These includes sodium-bearing phosphates and sodium-rich carbonates, sulfates, chlorides and fluorides formed during evaporation of a late-stage brine that existed in the earliest history of the Solar System. These minerals are largely unstable in the Earth's atmosphere, explaining their near absence in analog meteorites recovered after their fall to Earth. These minerals and their associated sodium-rich brine are an ideal environment for formation of complex prebiotic organics that were the first step on the path to life.

Microdynamic behaviour of salt rocks: insights from numerical simulations

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ABSTRACT

Rocksalt, primarily composed of halite, flows in a viscous manner in the solid state, significantly impacting the evolution of sedimentary basins and orogens. Salt flow is also key for the energy transition, since salt caverns are used to store Geo-Energy products. Full-field numerical simulations provide a powerful approach for understanding the deformational behaviour of evaporites and other rocks in a variety of deformation conditions (kinematics of deformation, temperature, etc.). The coupling of a viscoplastic full-field approach (VPFFT) with the ELLE numerical simulation platform (www.elle.ws) allows analysing halite rheology by considering the interplay between deformation accommodated by dislocation glide, intracrystalline recovery and several dynamic recrystallization processes, including subgrain rotation recrystallisation and grain boundary migration. The proposed approach aims to understand the microscale behaviour and evolution of halite under different deformation conditions, and how it controls the macroscopic behaviour and physical properties of the rock. In particular, we present results of numerical simulations that aim to (i) analyse the impact of dynamic recrystallization processes on pure rock salt under different temperatures, (ii) understand the influence of the kinematics of deformation on the microstructural evolution of pure rock salt, and (iii) assess the dynamic recrystallisation behaviour of two-phase systems composed of halite and a second hard phase (being e.g., carbonate or clastic grains).

The results reveal that temperature governs the competition between grain size reduction, driven by dislocation glide and subgrain rotation recrystallisation, and grain growth, associated with grain boundary migration recrystallisation. However, the crystallographic preferred orientation (CPO) is similar regardless the temperature for the same deformation conditions. The models also show how the kinematics of deformation can be partially inferred from the resulting deformation microstructure. Finally, the presence of a second hard phase causes the amplification of strain localisation, grain size reduction and a weakening of the CPO intensity. This study improves our understanding of rocksalt deformation and shows how aspects such as the kinematics of deformation and temperature can be inferred from the resulting microstructure.

3D forward models of salt flow and deformation in the Gulf of Mexico

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ABSTRACT

Numerical modeling methods can be used to study salt structures for various purposes. On one hand, three-dimensional geomechanical modeling approaches are widely used to estimate deformation in and around salt structures by simulating the instantaneous stress field associated with their complex present-day geometries. Such models help improve predictions and mitigate risks associated with engineering operations in these regions.

On the other hand, numerical models that simulate salt deformation over geological timescales can provide insights into the influence of different geological processes on the formation of salt structures. Forward numerical models of salt tectonics typically begin with simple initial geometries—such as a flat salt layer—which evolve into relatively complex salt structures through the interaction of sedimentation, tectonics, and salt flow.

Here, we present an alternative numerical modeling approach that starts from present-day complex geometries and runs forward in time to better understand 3D salt flow and deformation patterns. We use the northern Gulf of Mexico as a case study, a region characterized by the presence of allochthonous canopies—salt mobilized and emplaced at stratigraphic levels above its original depositional layer—forming some of the most complex salt-related geometries. Our simulations reveal intricate 3D salt flow, leading to complex subsidence and uplift patterns reflected on the seafloor. They also demonstrate the significant impact of highly irregular base-of-salt (canopy) topography and salt availability on seafloor deformation.

Recent advances in numerical modelling of salt basins and salt tectonics – from entire basins to diapir-minibasin scale

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ABSTRACT

Rifts and rifted margins are often associated with widespread and thick evaporite (salt) basins, typically formed during the final stages of rifting, immediately prior to continental breakup. These types of salt basins are often characterized by major salt tectonics, mostly attributed to gravity-driven salt flow and characterized by kinematically-linked domains of updip extension, translation and downdip shortening. However, the relative contributions between these processes as well the role of rifting and rifted margin architecture on salt deposition and tectonics are still a topic of debate on salt basins worldwide. In addition, the role of salt stratigraphy and intra-salt heterogeneity on basin-scale salt flow and the internal and external complexity of salt bodies is still a largely unresolved issue on the topic of salt basins. This is of outstanding scientific and societal relevance for the use of salt basins and salt structures in the context of energy transition, for storage (e.g., H2, CH4, nuclear waste), geothermal energy and mining. In this overview, we present results from 2D thermo-mechanically coupled finite-element modelling at the scale of entire conjugate margins to local, diapir-scale where we investigate the geodynamic context, geometry and evolution of late syn-rift salt basins. We focus on addressing the following key issues: i) the interplay between rifting and salt basin geometry with syn- to post-rift salt tectonics for different types of rifted margins, ii) the role of different post-salt lithologies and sedimentation rates on basin-scale salt flow, diapirism and minibasin formation, and iii) the role of variable intra-salt stratigraphy on the external and internal complexity of deformed salt bodies. The results are comparable to various salt-bearing rifted margins, including the South-Central Atlantic, the Gulf of Mexico and the Red Sea, and at a diapir-scale to the North Sea and onshore salt basins in Europe, ultimately helping us understanding their genesis, and evolution.

Framing the modelling experiments that evaluate the global impact of the Messinian Salinity Crisis

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ABSTRACT

Salt giants have the potential to perturb the climate via both chemical and physical processes: 1) the precipitation and weathering of gypsum changes ocean chemistry, impacting the carbon cycle; and 2) restricted exchange between marginal basin and the ocean leads to contrasting water density across the gateway, modifying ocean thermohaline circulation. However, Earth system models have yet to include these processes, making it challenging to evaluate the global impact of salt giants. Recent records generated from Integrated Ocean Discovery Program (IODP) Expedition 401, which drilled on both sides of the Gibraltar Strait, combined with data from IODP Expedition 397 on the Portugues margin refine existing reconstructions of gateway exchange before, during and after the Messinian Salinity Crisis (MSC, 5.97-5.33 Ma). These cores record Mediterranean outflow, its changing density, its powerful precessional pulse and changes to the gateway itself. Quantifying these Late Miocene Mediterranean density changes is a critical first step towards modelling their thermohaline consequences. By combining the updated gateway reconstruction with constraints from the evaporite sequences preserved within the Mediterranean, we provide a conservative estimate of the calcium fluxes resulting from gypsum precipitation and weathering. These fluxes can inform biogeochemical model experiments to explore the broader global impacts of the MSC (see presentation by Markus Adloff).

Global carbon cycle signals of the Messinian Salinity Crisis in a spatially-resolved Earth system model

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ABSTRACT

The Messinian Salinity Crisis (MSC, 5.97-5.33 Ma) is recognised as a period of dramatic regional environmental change. Shields & Mills (2021) showed that gypsum precipitation and weathering can theoretically perturb the global carbon cycle; however, the influence of specific salt giant formation events on global environmental change, as recorded in the geologic record, is largely unexplored. Building on new Ca flux estimates for the MSC, derived from the extent of gypsum deposits and updated constraints on Mediterranean outflow (see presentation by Rachel Flecker), we use the Earth system model cGENIE to investigate the temporal and spatial consequences of Ca deposition and weathering during the MSC. cGENIE is widely employed to interpret proxy records and study past marine biogeochemical cycling in a 3D ocean. Here, we examine how changes in seawater chemistry in the model affect the global carbon cycle and climate change. Our results show that even conservative estimates of Ca fluxes associated with the MSC lead to significant shifts in the carbon cycle and climate. These shifts help explain features observed in proxy-based reconstructions of regional and global Earth system change, including the limited data available on ocean [Ca2+] variations.

Model of the impact of basin restriction on the marine biodiversity

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ABSTRACT

The Messinian Salinity Crisis (MSC) was the most extreme paleoenvironmental perturbation that has ever taken place in the Mediterranean and resulted in the formation of one of the most recent and the best studied salt giant in Earth's history. Approximately 7 million years ago, the straits connecting the Mediterranean Sea to the Atlantic Ocean started to restrict, and by 5.5 million years they closed. High-amplitude fluctuations in both temperature and salinity gave place to a hypersaline isolated Mediterranean, where marine organisms struggled to survive. In our recently published studies, we assembled and revised the marine fossil record from before and after the crisis in order to quantify the effect of the crisis on the biodiversity of the Mediterranean. We documented for the first time a clear perturbation of the biota even during the restriction phase, as well as a high degree of reorganisation of the marine ecosystem after the crisis, with most of the change in the taxonomic composition attributed to species turnover. Only a handful of endemic Mediterranean species may have survived the crisis. Furthermore, the present-day NW-to-SE decreasing gradient in species richness first appeared after the MSC, suggesting that neither the distance from the Atlantic source nor the temperature gradient are the causes of the gradient today. Considering that salt giants have formed since the Proterozoic, we propose a model to explain the mechanisms through which the geological processes leading to salt giant formation also result in the disruption of marine functional connectivity patterns, with important macroevolutionary implications. We use the results of this study to demonstrate these impacts in the case of the Mediterranean MSC. Finally, we discuss how this model could be transferred to other salt giant settings.

Puzzling together the Mediterranean drawdown during the Messinian Salinity Crisis

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ABSTRACT

Seafloor erosion evidence from seismic reflection surveys and chloride isotopic measures suggest that the precipitation of a million cubic kilometers of salt during the Messinian salinity crisis (MSC) involved an evaporative sea level drop in excess of a kilometer. However, the puzzling sedimentary record that formed afterwards (the Lago-Mare formation) yields conflicting levels of desiccation, ranging from a full exposure of most of the Mediterranean seafloor (based on shallow sediment found in the abyss) to a nearly-full Mediterranean scenario (as suggested by similar, fresher-water deposits ubiquitous along the coastline). Using a landscape evolution model of the drawdown stage constrained with climate and sediment budgets, we show that the propagation of an erosional wave into the surrounding continents added a gradual sea level rise to the climatic oscillations of the Mediterranean. This retrogressive fluvial incision of the spillways of the Paratethys and the Pannonian basins also explains the Mediterranean transition to fresher water conditions during the MSC. Put together, these independent results provide a model for the evolution of sea level during the MSC that is consistent with the ubiquitous Lago-Mare, with the dynamics of seaway erosion and with the abrupt transition to open marine conditions during the Zanclean Megaflood.

Trace and rare earth element (REE) geochemistry of salt formations: indication and identification

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ABSTRACT

The geochemistry of trace elements and REEs in salt formations can be used to trace the origin of the salt and the environmental conditions under which it formed. Marine evaporites often have a characteristic REE signature with higher concentrations of LREEs and relatively low HREEs, reflecting the chemical composition of seawater. Continental salt deposits, on the other hand, may show more variability due to differing sources of brine and evaporation conditions. Moreover, the chemical composition of salts can be linked to the stage of evaporation. Early-stage evaporation might produce salts rich in elements like calcium, magnesium, and potassium, while later stages (as the brine becomes more concentrated) can lead to the precipitation of salts with higher concentrations of sodium and chlorine. If the salt formation has been affected by hydrothermal fluids, the REE signature may reflect the influence of these fluids, which could be enriched in specific REEs or trace elements depending on the temperature and chemical composition of the fluid.

The concentration and distribution of certain trace elements and REEs can provide clues about paleoenvironmental conditions, such as the salinity, temperature, and chemistry of the ancient waters that contributed to salt deposition. Some trace elements, like lithium, boron, and potassium, are economically valuable. Understanding their geochemical behavior in salt formations can aid in the exploration of these resources. Similarly, certain REEs might be of interest for rare earth mineral exploration, as they can be concentrated in salt deposits under specific conditions. To trace and identify these elements, various geochemical techniques can be employed with special emphasis of Inductively Coupled Plasma Mass Spectrometry (ICP-MS), which is used for analyzing trace and rare earth elements in salt samples with high sensitivity.

The trace and rare earth element geochemistry of salt formations offers critical insights into the depositional history, environmental conditions, and economic potential of these deposits. By analyzing the distribution and concentration of these elements, scientists can reconstruct the conditions under which the salts formed and identify potential resources for further exploration.

The History of Ocean Chemistry from Evaporites: Advancing Beyond the State of the Art

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ABSTRACT

Evaporites have been instrumental in shaping our understanding of ocean chemistry throughout Earth's history, with direct relevance to the evolution of the environment, climate, and life. Microscopic fluid inclusions trapped within the crystal lattice of evaporitic minerals, particularly halites, provide a unique sample of ancient seawater, offering a snapshot of the composition of past oceans. Pioneering work by Lowenstein et al. (2001) and others demonstrated the potential of the fluid inclusion archive to provide fundamental insights into past major ion composition of seawater. However, it also highlighted challenges, such evaporitic influences on seawater chemistry and secondary effects, that need to be constrained to robustly derive past seawater compositions. In this presentation, I will showcase recent developments in the reconstruction of seawater chemistry from fluid inclusions, including minor element concentrations and their isotopes, and highlight their implications for advancing our understanding of the Earth system.

Nature and Significance of evaporites in the northern Afar (Ethiopia): from Recent salt lab to deep drilling

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ABSTRACT

The understanding of large evaporite deposits is poor and still controversial due to the absence of modern analogues. Especially, the mechanisms of formation, hydrological and environmental conditions, geobiosphere interactions in salt deposits, geobiogeochemical cycles as well as rates of evaporite precipitation remain highly ambiguous. The Danakil Depression, localized in the Afar rift (northern Afar, Ethiopia) and being close to continental break-up, host thick Pleistocene to Holocene evaporites with deposition continuing today. As such, the Danakil Depression forms a unique Recent lab to study salt formation, gypsum deposition and its interaction with tectonic processes, volcanic events, eustatic sea-level change and the geobiosphere. The Recent age of the Danakil evaporites along with the availability of very high temporal resolution records offer new insights in the formation of those enigmatic deposits.

Multi-proxy analyses on cores in the central part of the Danakil Depression witness restricted marine conditions since the last Late Pleistocene marine incursion resulting in the near-desiccation of the basin with the deposition of thick halite and Potash deposits. The Recent basin floor represents a large active halite-floored saline pan with the presence of hypersaline lakes but also hydrothermal brine pools, sulfuric acidic springs, and fumaroles through the direct interaction between magmatism, sedimentary and salt processes. This allows studying life-salt interaction and biogeochemical cycling in polyextreme conditions across geothermal gradients.

Subsurface seismic data show the presence of distinct syn-rift seismo-stratigraphic units probably representing similar evaporite lithologies as observed for the Late Pleistocene until a depth of 2.2 km. However, the origin and nature of those sedimentary units remain to be unveiled. The ICDP ADD-ON project aims to drill through the syn-rift sedimentary record in the central part of the Danakil Depression which will shed new light on the understanding evaporite formation in extreme rift settings and other Salt Giants on Planet Earth.

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Connection Pathways of Marine Incursions in an Active Rift Basin: The Danakil Depression, Northern Afar

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ABSTRACT

Evaporites constitute an important component of rifts and rifted margins. They form unique sedimentary archives at both basinal and microfacies scale. The integration of subsurface seismic datasets with cores, outcrop data and microfacies analysis can unravel the relative interplay of tectonic, volcanic and eustatic controls on basin development and aid in the understanding of evaporite formation. Whilst most existing research into salt giants has focused primarily on ancient evaporites often buried under kilometers of sediments, recent analogues are often missing. The Danakil Depression (northern Afar, Ethiopia) is an active rift basin close to continental break-up, and as such the mechanisms involved in evaporite formation can be studied in detail. Current understanding, based on outcrop observations at the margins of the Danakil Depression, suggests that at least four cycles of flooding occurred during Pleistocene times. However, the location of the gateways and nature of facies changes within the central part of the basin are thus far poorly constrained. This study aims to better understand the mechanisms related to evaporite formation within the Danakil Depression through the integrative use of outcrop data, well data and subsurface seismic datasets. Objectives are to 1) constrain and localize the gateways between the Red Sea and the Danakil Depression during the Pleistocene, and 2) constrain the palaeohydrological evolution of the Danakil Depression at that time. Based on the seismic datasets in correlation with the well data, an integrative seismostratigraphic framework is established. Results evidence the tight relationship between prograding depositional units, channel fill deposits and salt formation and provide a unique insight into the development of clastic and evaporative deposits in an extensional regime.

Salt-Sediment interaction during Mesozoic evolution of the Polish Basin

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ABSTRACT

The Permian-Mesozoic Polish Basin belonged to the system of intracontinental basins that developed within the current western and central Europe. Following Permian extension and volcanism, it experienced long-term Mesozoic thermal subsidence, and then was subjected to the Late Cretaceous to early Paleogene Alpine inversion. Sedimentary infill of the Polish Basin starts with the Rotliegend (Cisuralian – lower Lopingian) clastics and Zechstein (upper Lopingian) evaporites and carbonates. Zechstein salts gave rise to extensive system of salt structures – pillows and diapirs – that evolved throughout entire Mesozoic. High-quality seismic data calibrated by deep wells imaged very diverse geometric relationship of salt structures and surrounding clastic and carbonate depositional systems. In Late Triassic, due to increased sub-salt extension, numerous salt extrusions (salt glaciers) formed within local extensionally-controlled supra-salt subsidence centers. They are characterized by significantly increased thickness of Upper Triassic Keuper series that contain evaporitic layers, interpreted as redeposited Zechstein evaporites. Late Jurassic growth of salt pillows led to formation of local elevations within Jurassic shallow, warm epicontinental sea above which carbonate buildups (reefs) grew. Grand finale of salt-sediment interaction was associated with Late Cretaceous regional compressive reactivation of salt diapirs during basin inversion. Compressionally driven growth of salt diapirs led to formation of local elevation on sea bottom where locally thinned growth strata, sometime punctuated by local unconformities. Upper Cretaceous syn-inversion succession recorded several phases of inversion-related growth of diapirs, spanning Turonian – Maastrichtian. Locally, also contourites were deposited in vicinity of anticlines cored by compressionally reactivated salt diapirs.

Anomalously thick anhydrite networks in the Zechstein of the Southern North Sea - insights from seismic forward modelling

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ABSTRACT

High quality seismic reflection data can now play essential role in the study of the large-scale evaporitic accumulations and multi-layered sequences that characterise many salt giants. One of the best known examples is the polycyclic Zechstein Supergroup (ZSG), with its individual cycles recognised across the southern Permian Basin from north-east England to Poland. In this study, we have focused on the major anhydrite unit (also known as “Hauptanhydrit”) within the Z3 cycle of the ZSG, which exhibits significant lateral heterogeneity. It is an exception to the generally isopachous nature of evaporite deposits within the basin. Over the past decade, the mapping of the Anomalously Thick Zones (ATZs) within the Zechstein Main Anhydrite (Z3a) in the Southern North Sea (SNS) has been achieved through the 3D seismic data analysis supported by well data. Recent studies have shown that the thick zones of the Z3a form basin-scale network extending from the UK to Germany and Poland. The amplitude of the Z3a top reflection shows significant variation with interval thickness. As a result, it frequently reaches or approaches the peak of the seismic tuning. We aimed to calibrate the ATZs and establish the effective vertical and lateral seismic resolution of the anhydrite networks and from these constrain their cross-sectional geometry. The geometry is critical for resolving the much debated origin of these features. We have applied full-wave seismic forward modelling based on seismic and well log data as well as geological interpretations from the SNS. The results allow the verification of the highly variable seismic response of anhydrite networks in terms of their petrophysical parameters, dimensions and geometry. The results provide invaluable input for the broader discussion of genetic mechanisms of the ATZs. The seismic and well data set used in this study contains information provided by the North Sea Transition Authority and/or other third parties.

Radiocarbon Dating and InSAR Mapping of Quaternary Salt Diapir Uplift in the Romanian Eastern Carpathians

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ABSTRACT

Salt tectonics plays a fundamental role in shaping geological landscapes, driving deformation processes across both historical and contemporary timescales. In the Romanian Eastern Carpathians, salt movement has been extensively studied for its relevance to resource extraction and hydrocarbon geology. However, a significant gap remains in understanding the timing and rates of salt diapir uplift in humid continental climates.

This study integrates radiocarbon dating with geomorphological analyses to quantify the Quaternary uplift rates of salt diapirs, focusing on the Manzalesti salt diapir, Europe's largest rock salt outcrop. We provide direct constraints on salt uplift rates over the past ~750 years through radiocarbon dating. Our findings reveal that the average relative uplift rates over this period align closely with recent InSAR-derived vertical velocities (2018–2023), offering new insights into salt diapir dynamics.

Beyond its geological significance, this research has critical societal and industrial implications. It addresses hazards associated with salt movement, such as sinkholes and landslides, while also exploring the potential of salt caverns for energy storage, including hydrogen storage. By integrating radiocarbon dating with digital outcrop models and InSAR, this study presents an approach to assessing salt tectonics in the Romanian Eastern Carpathians, contributing valuable data for scientific exploration and practical applications in the energy transition.

Badenian Salt Deposition in the Carpathian Region: Insights from Geochemical and Sedimentological Studies

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ABSTRACT

The results of geochemical and sedimentological studies have allowed for the determination of the origin of brines and the influence of continental water inflow as a significant factor in the sedimentation of evaporites in the salt basins of the Carpathian region. Salt crystallization began in a marine environment, from waters with a chemical composition similar to modern ocean water. During halite precipitation, both normal-salinity seawater and meteoric waters entered the salt basin, mixing with the brines. The influx of these freshwater sources caused partial dissolution and redeposition of salt. It was found that the temperature of bottom brines was consistently lower than that of surface brines, and the temperature distribution aligns with observations of modern water columns in deep marine basins, resembling conditions in the Dead Sea. The analysis of extent of evaporite facies in the western part of the Carpathian Foredeep indicates a direct relationship between the intensity and type of evaporite sedimentation and the morphology of the pre-Badenian basement. It reflects the existence of several morphological thresholds in the substrate. These thresholds formed shallow areas where sulfate crystallization occurred, dividing the saline basin into sub-basins and hindering the flow of denser, saturated brine currents between different parts of the basin.

Age and mode of the Badenian Salinity crisis

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ABSTRACT

Massive evaporites were deposited in the Central Paratethys Sea during the Badenian salinity crisis (BSC). We present chronological data that indicate this catastrophic event started at 13.8 and terminated at 13.4 Ma, respectively. A global sea-level drop of 50–70 m likely restricted the western gateway to the Mediterranean to such an extent that halite formed in the Central Paratethys. Subsequently, the progressive opening of the eastern gateway to the Black Sea reduced the salinity in the Central Paratethys providing a novel physics-based explanation for the change from evaporitic to marine to brackish-marine water conditions in a marginal basin.

From Neotethys to Paratethys: Changing marine gateways across the Anatolian Landmass

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ABSTRACT

The Neotethys Ocean was an ancient ocean that existed between the continents of Gondwana and Laurasia during the Mesozoic era. It evolved as a result of plate tectonic movements and played a key role in shaping the geography of present-day Eurasia, Africa, and the Middle East. Progressive convergence led to closure of oceanic basins and development of major Neotethyan subduction zones, eventually contributing to the Alpine-Himalayan orogeny and the uplift of the Iranian and Anatolian plateaus. Final, the Neotethys oceanic lithosphere subducted and Arabia collided with Eurasia, and the preserved remnants of the Neotethys were trapped, forming landlocked seas like the Mediterranean in the south and the Paratethys (Black Sea-Caspian Sea domain) in the north.

During the Oligocene to Pliocene, the Paratethys Sea covered large parts of Central and Eastern Europe as a semi-isolated sea or megalake separated in subbasins due to the uplift of the Alps, Carpathians, Pontides, and Caucasus. At the southern margin, the Anatolian landmass formed a shallow barrier controlling Paratethys-Mediterranean connectivity. Tectonic uplift and global sea level lowering restricted the Paratethys at the beginning of the Oligocene. Throughout geological time, climate changes and tectonic activity caused Paratethys to shrink dramatically and led to hypersaline conditions during the Badenian Salinity Crisis (13.8-13.4 Ma) and other evaporitic episodes in the Carpathian foredeep.

This study presents preliminary information for a detailed stratigraphic investigation planned in a key section along the Central Black Sea coast (Sinop region, Türkiye) where a significant record of the late Eocene to Middle Miocene is exposed. The research aims to explore the rise and demise of the Paratethys and its connections to the open seas throughout the Oligo-Miocene times. Detailed stratigraphic, geochemical and isotopic studies are planned to reveal how the vast ocean evolved into smaller, isolated water bodies over millions of years.

Three million years of salt deposition in the Salar de Uyuni (Bolivia)

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ABSTRACT

Salar de Uyuni (Bolivian Altiplano) is the largest salt flat in the world. Lacustrine carbonate rocks representing higher lake-water levels in the basin crop out on the margins of the Salar and on inselbergs within the salt flat. However, these exposures are limited and do not permit a thorough study of the sedimentary infill. Drill cores remain the best method to directly access the sedimentary record that underlies the salt pan. Petrological and mineralogical analysis of a new 460 m drill core has allowed us to identify the following lithofacies: massive halite, banded halite, interstitial halite, gypsum, marls and carbonate, volcanic ash, clays, and red silts. These lithofacies represent a succession of saline sedimentary environments varying from mud flat, salt pan, perennial shallow saline lake, and perennial deep saline lake. The chronology of the core was established by 40Ar/39Ar dating of sanidine phenocrysts in seven tuffs intercalated in the section, combined with magnetostratigraphy. The results demonstrate a long sedimentary history from the middle Pliocene to the present. Our dates indicate an extraordinary acceleration of sedimentation rates during the late Pleistocene. The correlation of this core with two other published cores (170 m and 220 m deep) indicates lateral facies variations in the thickness of the different salt units. The Salar de Uyuni is a complex sedimentary system strongly affected by diluted river discharge, as well by exposure of nearby Mesozoic salt diapirs. This study highlights the spectacular variations in sedimentation rates during halite deposition and the evidence of a dominant evaporitic environment during the last 3 million years in the Bolivian Altiplano.

Modern halite deposition in the Dead Sea as an analog for the formation of salt giants

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ABSTRACT

Layered halite sequences were deposited in deep hypersaline basins throughout the geological record. These sequences are of research interest for hydrocarbon extraction, mineral exploration, tectonics and structural geology and paleoenvironmental research. Modern analogs and the processes leading to deposition of thick halite sequences were studied only through analyses of the common modern, shallow environments, which are fundamentally different in their nature from halite -depositing, deep waterbodies. Thus, the spatiotemporal evolution of halite sequences remained ambiguous. In this talk, I will present, the knowledge that was accumulated in recent years on the active precipitation of halite layers at different spatial and temporal scales from the only modern analog in the world for deep, halite-precipitating basin; the hypersaline Dead Sea in Israel. This includes characterization and quantification of the impact of the seasonal thermohaline stratification and freshwater and sediment discharge on halite saturation and deposition, and on the characteristics and long-term accretion of halite sequences. In addition, throughout the talk, the implications of these results to the geological record will be presented.

Unveiling Deep-Time Microbial Ecosystems: Biomarker Evidence from ~820 Ma Hypersaline Environments

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ABSTRACT

This study explores deep-time microbial ecosystems through biomarker analysis of ~820 Ma evaporites from the Gillen Formation, Bitter Springs Group, central Australia. These Neoproterozoic deposits provide crucial insights into Precambrian halophilic communities and their potential role in mineral precipitation.Solvent extraction of alternating laminae of dolomitized microbial mats and anhydrite yielded thermally well-preserved hydrocarbon biomarkers. The presence of 2,6,10,14,18-pentamethylicosane, squalane, and biphytane breakdown products in anhydrite-rich sediments provides the oldest current evidence for halophilic archaea. Linear correlations between isoprenoid concentrations (normalized to n-alkanes) and anhydrite/dolomite ratios reveal microbial consortia fluctuations with changing salinity levels. Halophilic archaea dominated during high salinity periods, while bacteria prevailed during carbonate formation. The presence of 2,6,10,15,19-pentamethylicosane (PMI) and crocetane indicates methanogen activity and archaeal presence during varying salinity conditions. Isotopically depleted n-C17 revealed cyanobacterial presence across all salinity regimes. The biomarker assemblage resembles modern hypersaline cyanobacterial mats, suggesting a broadly constant community composition since the Neoproterozoic, albeit lacking evidence for eukaryotes. This study provides insights into ancient hypersaline microbial ecology, contributing to our understanding of Earth's early biogeochemical cycles.

Paleoenvironmental evolution of the Eastern Paratethys: Tracing the Tethys Ocean legacy through geochemical proxies

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ABSTRACT

During the Oligocene to Miocene, the Paratethys Sea emerged as the northern offshoot of the Tethys Ocean, separated from the Mediterranean by the Alpine-Himalayan mountain range. Its history was characterized by the opening, restriction, and closure of marine gateways, resulting in significant paleoenvironmental changes, including episodes of anoxia and extreme salinity fluctuations. This study investigates the paleoenvironmental evolution of the Paratethys Sea by focusing on variations in salinity and paleoventilation through advanced geochemical analyses of key sections (Belaya, Panagia, Zhelezhny Rog) in the northern Caucasus and Taman Peninsula of Russia, spanning 42 to 4 Ma. Our results indicate that Paratethys was influenced by both global and local events, with regional factors becoming increasingly significant as isolation and fragmentation progressed. Paleoventilation proxies reveal two main episodes of anoxia: the Kuma Anoxic Event, associated with the Middle Eocene Climatic Optimum (MECO) and exhibiting oceanic anoxic signatures; the Maikop Anoxic Event, coinciding with the Eocene-Oligocene Transition (EOT) and lasting until the Middle Miocene Climatic Optimum (MMCO), reflecting characteristics of an enclosed sea; and a weaker, less stable suboxic-anoxic episode in the late Miocene, associated with Megalake Paratethys. Paleosalinity proxies depict both transitions from marine to brackish conditions, such as the late Maikop salinity decrease and significant short-lived marine episodes, such as the MMCO-related mid-Langhian flood (14.8 Ma), the Badenian-Sarmatian extinction event (12.65 Ma), and the Intra-Maeotian Event (6.8 Ma). These findings emphasize the critical role of marine connectivity as a trigger of salinity and ventilation changes in the Eastern Paratethys's evolution, laying the groundwork for future studies on restricted basins.

Gypsum deposits in Albania, their types and practical importance

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ABSTRACT

Evaporites are widely distributed in Albania and belong to two different ages: those of Miocene age and the Permo-Triassic (?) or Upper Triassic characterized by complicated diapirism. The Miocene evaporites representing the so-called Messinian crisis are widespread within the Adriatic lowlands and are represented by gypsum and halite and their stratigraphic position and the relationships with surrounding rocks are very clear. Large surface outcrops of Miocene evaporites are found from Manza to Panaja (Vlora), this type of deposits having a wide distribution throughout the Mediterranean region. The structure hosting the gypsum and halite deposits appears as a predominantly clayey package with a thickness of up to 250 m, within which up to 11 layers of gypsum with a thickness of 0.5 - 20 m have been identified. In the upper part of the package, the halite level is approximately 50 - 60 m above the gypsum level.

The Permo-Triassic (?) or Upper Triassic diapiric type is widespread within the Ionian and Korabi geological zones. These formations represent thrusts from depth to the surface through strong overthrusting (longitudinal) and transverse tectonics. The diapirs have a size of up to 210 km2 (Dumrea diapir) and a thickness of over 6000 m. The stratigraphic position of these deposits is unclear and the relationships with the surrounding rocks are very complicated. In the case of the Dumrea diapir, the age was determined as Upper Triassic based on palynological data. This type is associated with important deposits of halite, as well as tuffs and basic volcanic rocks, but in the case of the latter, deposits the relationships are uncertain. These diapirs are of great interest for lithium exploration, as well as the thermal waters hosted by these deposits which are important sources of thermal energy and have curative properties. These sedimentary deposits are also characterized by an important karstification, where the 85 karst lakes within Dumrea diapir represent important tourist attractions. In terms of geohazards, these diapirs require special attention precisely because of these strong karstification phenomena, which are not evident on the surface and which pose a great risk to habitation and infrastructure. Until now, these gypsums have been used for the production of cement and plaster, while alabaster has been used for the production of decorative materials.

The crucial role of human capital in the sustainable development of the raw materials sector

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ABSTRACT

Critical raw materials (CRMs) are indispensable for green and digital transformations, enabling advancements in renewable energy, electric vehicles, and communication technologies. Albania, endowed with rich mineral resources such as chromium, iron-nickel, copper, and evaporites (e.g., gypsum, anhydrite, and halite), has significant potential to strengthen its role in European supply chains. While CRMs are vital, the inclusion of evaporites highlights their importance in construction, agriculture, and environmental applications. However, maximizing this potential requires strategic investments in human capital.

The transition to sustainable mining and resource management demands professionals equipped with interdisciplinary skills. Young engineers, geoscientists, and sustainability experts are key to transforming the industry from a traditional extractive model to a high-tech, eco-friendly sector. Training in areas such as environmentally responsible extraction, advanced resource processing, and CRM-specific applications is vital. Simultaneously, the potential of evaporites as essential materials in economy must be integrated into education and innovation strategies.

Vocational education and training (VET) tailored to mining and processing needs are crucial. Programs that incorporate evaporite applications alongside CRM-focused training can bridge skill gaps, fostering a workforce capable of driving innovation. The RIC Center's proposal to establish specialized classes near high schools and to offer training in areas such as mineral processing, sustainable mining, and evaporite utilization exemplifies this proactive approach.

The EIT Raw Materials Regional Innovation Center plays a pivotal role in aligning education, research, and industry needs. By promoting specialized training, enhancing collaborations with academia, and introducing entrepreneurial thinking, the Center aims to create a skilled workforce ready to meet the challenges of modern mining and resource management. Initiatives like mentorship networks, targeted university programs, and open classes for high school students will emphasize the dual importance of CRMs and evaporites.

Looking forward, collaboration between academia, industry, and innovation hubs can unlock Albania’s potential, positioning the nation as a leader in sustainable resource management. By integrating evaporites into the broader CRM narrative, Albania can diversify its contributions to European supply chains while fostering a new generation of professionals to lead the industry. Through strategic partnerships, Albania can transform challenges into opportunities, advancing toward a resilient and sustainable future.

Experiential fieldtrips and transformative learning on iconic Messinian evaporite outcrop enhance climate change education among young Italian students

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ABSTRACT

The objective of raising awareness and take action about current climate change (SDG13, SDG6) cannot be fully achieved without a strategy that involves schools of all levels as much as possible. In fact, traditional knowledge dissemination does not emotionally involve the learner and thus fail to develop deep, personal involvement in the subject, nor the urge of taking action. This study presents the results of an analysis conducted among young students that took part in an outdoor activity entitled "Earth Sciences and climate change", in which, after an introductory meeting held in the classroom, a didactic excursion was planned to the Spiaggia dei Cristalli (Verduno, CN), an iconic outcrop allowing to explore Messinian deep marine sediments and gypsum deposits and to unravel the paleoclimatic clues they record, such as sea floor deoxygenation during periods of enhanced warming and the response of the marine biota to environmental changes. We adopted an inquiry-based method through a sensory exploration of the area that prompted participants to reflect on their own relationship with Nature and the role of humans in the current ecological crisis. The students' answers to the pre- and post-experience questionnaires show that the visit to the site was fundamental for learning some basics of stratigraphy, paleoceanography, paleoclimatology and sedimentology, as well as for effectively understanding how Earth Sciences systemic thinking applied to the study of past climatic changes helps to compare them with those taking place today and to address their causes and impacts. Our suggestion is therefore to foster geoscience education throughout the use of experiential fieldtrips as teaching tool, as they allow for a transdisciplinary and transformative education, which aligns geoscience education with the goals of education for sustainability: this will furthermore contribute to underline the importance of iconic geosites and their unique contributions for the understanding of Earth's past and its connection with a sustainable future for both humankind and non-humans (Gerbaudo et al.2022).

Drawing to visualize science: studying Microplastics in salts

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ABSTRACT

It is imperative to sensitize the population about microplastics (MP), especially children and young people. Through an interdisciplinary team formed by geologists and artist, we created a manual with instructions. We aim to Sustainable Development Goals 3, 4, 6 and 12, raising awareness on the presence of plastic in our lives, even in our food. We present laboratory protocols to study the presence of MP in table salts. Is intended to be applied either in schools with or without a regular chemistry lab or even at home. The interest of this project is also to create activities for Primary and Secondary teachers to help students the understanding and motivation on chemical and geological processes. The process of preparing, dissolving, filtering, observing and controlling the possible pollution is explained in a simple way. After the ideation of the protocols, is done an artistic process of drawing in different techniches, searching for a high level of iconicity to clarify all the tools and steps involved. Finally, we added short text to prevent misunderstandings. The whole project is accessible at http://www.ub.edu/sedimentary-geology/microplastics-salt, and the protocols are completely free to help dissemination. They can be downloaded to use them digitally or by printing them on paper.

Dissemination based on the interaction between science and art

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ABSTRACT

Dissemination of science can benefit from engagement with art. Artistic interpretation of scientific results can trigger a moment of surprise and curiosity in scientists and in the broader public. Art can also inspire scientific research.

In COST Medsalt I had the opportunity to work with the disseminating the project through artistic expressions. The sea salt crystal was chosen as a vehicle to communicate the project.

During a meeting in Sicily a dance performance was created based on electronic music composed of sounds produced in the salt pans. The dancers invited the researchers to come out from the conference room to attend the performance.

The knowledge related to the sea salt crystal was communicated through three short videos: Cosmos in sea salt crystal, Life in the salt crystal and Sea salt crystals in space. The contents of the videos visualize the geometries of the salt crystal, the life within it and the hypothesis of the presence of the salt crystal in the Universe.

In conclusion the video The Universe gleams in the salt crystal was created to express the strong bond between salt and man in the cultural landscape of the salt pans.

My role as a the link between researchers and artists required knowledge of both science and the artistic language and a capacity of dialogue and interaction.

Leonardo da Vinci expressed the role of art in the dissemination of science: ‘Art is the queen of all sciences communicating knowledge to all the generations of the world’.

Gypsum microbialite deposits: modern and ancient examples

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ABSTRACT

Gypsum microbialites are rarely documented and remain far less studied than their carbonate counterparts. These deposits form when a benthic microbial community traps and binds detrital gypsum sediments, and/or serves as the locus of gypsum precipitation. Most gypsum microbialites develop through in situ crystallization of gypsum within benthic microbial communities. The precipitation of gypsum is primarily due to the evaporation of Ca-sulfate-saturated water rather than direct biological activity. Gypsum commonly crystallizes on the surface of microbial mats, leading to their incrustation and lithification, which preserves the mat's morphology and forms what are known as gypsified microbial mats. Gypsum microbialites also develop alongside selenite (coarse crystalline) gypsum, forming selenite-gypsum microbialite deposits. They are hybrid microbialites.

Gypsum microbialites, including hybrid varieties have been documented in both modern and ancient locations. They were first identified in 1968 in the Badenian evaporites of Poland by Stanisław Kwiatkowski, who described them as gypsum stromatolites—layered, domed sedimentary structures of "algal" origin. The best documented ancient gypsum microbialites are found in the Messinian of Cyprus and the Badenian of Poland and Ukraine. Additional occurrences have been recorded in Miocene deposits from other Mediterranean countries, as well as Saudi Arabia, and Bulgaria. These occurrences are thought to form in shallow-water to semi-emerged environments in extensive marine evaporite basins. Modern gypsum microbialites have been observed in marine saline lagoons, salinas, saline lakes, and solar saltwork pans along the coasts of the Arabian Gulf, Red Sea, and Mediterranean, as well as in Venezuela, the Netherlands Antilles, Chile, and Australia.

Three-dimensional maps of salt structures from northwestern Poland

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ABSTRACT

Maps of salt structures were prepared by Tarkowski and Czapowski (2018). 3D maps of salt pillows in northwestern Poland were developed using the new and archived geophysical and borehole data. As a result of developing this data, the range and morphology of the pillows were verified. Maps of the roof and floor with the ranges of salt pillows were developed in Szczecinek, Strzelno-Toruń. As a result of the analysis of seismic images, local changes in thickness were also noticed, which may be a manifestation of a previously undetermined salt pillow. The preparation of detailed maps of salt structures can be launched in research to calculate resources and provide geothermal applications with thermal salt protection.

Tarkowski, R., & Czapowski, G. (2018). Salt domes in Poland–Potential sites for hydrogen storage in caverns. International Journal of Hydrogen Energy, 43(46), 21414-21427.

Stability of the chemical composition of rock and potassium salt solutions

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ABSTRACT

The purpose of stability tests is to determine the mechanisms of chemical reactions and transformations, determine their speed and stabilize the system. Each physicochemical system may be subject to constant changes over time. This study examined whether there are changes in the salt solution as a function of time, using the example of rock salt and potassium salt samples. Powder material was prepared from selected rock samples, which was then dissolved in distilled water, and the remaining water-insoluble part was mineralized in hydrochloric acid. Water solutions of rock salt with a concentration of 40 g/l and potassium salt with a concentration of 4 g/l were prepared. The salt solutions prepared in this way were stored in controlled laboratory conditions (temperature, humidity). Stability tests of the solutions were performed several times, at weekly intervals. The content of the following components was tested: chlorides, sodium, potassium, calcium, magnesium, sulfates, and the pH of the solution was measured. The composition was analyzed using various analytical methods, including: flame photometry, complexometry, argentometry, potentiometry, gravimetry. It was determined whether the potential waiting time of the sample for testing, e.g. several weeks, affects the results obtained. The results of chemical analyzes obtained in accordance with the adopted acceptance criteria were summarized and presented in tables and graphically.

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The trap method for monitoring hydrogen and soil gas leaks in underground gas storage (UGS) in salt caverns for environmental safety

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ABSTRACT

The underground storage of pure hydrogen or hydrogen-enriched natural gas in underground gas cavern storage (UGS) presents significant economic and environmental advantages. Hydrogen, as a clean energy carrier, enables efficient energy storage, supports renewable energy integration and reduces carbon emissions when used as a fuel. Additionally, blending hydrogen with natural gas can enhance energy security by optimizing existing gas infrastructure. However, despite these benefits, storing hydrogen underground presents unique challenges related to its high permeability and potential migration into the atmosphere. Unlike natural gas, hydrogen has the smallest molecular size, allowing it to diffuse through rock formations, salt deposits, and soil layers, increasing the risk of leakage. Due to its lack of adsorption, hydrogen can also escape more easily from storage reservoirs, making precise monitoring essential to ensure environmental safety. Trap-based detection method was developed to improve the monitoring of hydrogen migration. This innovative approach involves modifying the piezometer system, allowing for targeted sampling and precise gas analysis. The trap's materials were carefully selected to ensure resistance to hydrogen permeability and external conditions. Periodic sampling from the hydrogen trap is analyzed using gas chromatography, enabling early leak detection. By implementing a strategically designed monitoring grid, this approach not only mitigates risks but also ensures that the benefits of underground hydrogen storage outweigh potential environmental concerns. The newly developed trap-based method represents a crucial advancement in safely integrating hydrogen into underground energy storage systems, supporting the transition toward a more sustainable energy future.

The South Pyrenean Potash Basin as an analog for the Messinian Salt Giant

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ABSTRACT

No modern analogs exist for basinwide evaporite deposition, only marine salinas and a few saline lakes are useful as modern examples for old evaporite deposition. Well-documented ancient evaporitic deposits can help to understand the evaporitic sedimentation in poorly documented deposits. We show here the example of the Late Eocene South Pyrenean Potash Basin (SPPB), which can be used to assess sedimentary processes during the Messinian Salinity Crisis (MSC) in the Mediterranean Basin. Although at different scale, the SPPB presents some similitudes with the MSC in terms of lithofacies and facies distribution. Preevaporitic marginal reefs with equivalent marls deposits towards the center of the basin occur in the SPPB. Once the basin enters into an evaporitic stage, these open marine sediments are overlain by stromatolitic deposits representing an increase in salinity and a sea level fall. A gypsum belt unit distributed in a more internal zone of the basin shows stromatolites, megaselenite cones and large gypsum crystal pseudomorphs. Laterally to the center of the basin, a salt unit covers a basal anhydrite deposit. This salt unit is 10 times thicker than the marginal gypsum. The presence of anhydrite stromatolites in the central part of the basin suggests that the water level decreased substantially exposing the main part of the basin before the salt deposition. The relationships between the marginal gypsum deposits and the central halite is difficult to establish because occur geographically 30km apart and only the marginal deposits crop out. Above the lower halite unit, a K-Mg rich chloride unit (potash) was deposited, this unit indicates a hyper-concentrated brine interpreted as deposited in a shallow setting. Borehole and mining information from the SPPB show that the thickness of the basal anhydrite and salt deposits varies across the basin and between the two known depocenters.

The cooling event Mi3b symptoms of the Middle Miocene Climate Transition period in the Skawina Formation deposits (Rybna 90, Chełmek s-15; the Carpathian Foredeep; Poland) – stratigraphic implications

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ABSTRACT

The Middle Miocene Climate Transition period includes several episodes of climate cooling. Badenian deposits in the western part of the Carpathian Foredeep in Poland contain fossil records of some of them. One of the events was the largest in scale (Mi-4) and allowed the sedimentation of evaporites, which are considered isochronous/near-isochronous and serve as an important correlation level. Previous studies of foraminiferal microfauna conducted in the Skawina Formation sediments made it possible to read the paleoecological record of two slightly older events Mi3a and Mi3b (Gonera 2018). The Mi3b event coincides with the border of the Moravian/Wielician in the Central Paratethys (global Langhian/Serravalian) and regional assemblage zones IIB/IIC in Poland. Research on foraminifera in analogous deposits in the Rybna 90 and Chełmek s-15 boreholes allowed for the determination of this boundary. In the sediments occurring on/above this boundary, foraminifera (IIC) and accumulations of gypsum crystals found in the residuum. This is another example of the local occurrence of evaporite sedimentation symptoms in Poland in this stratigraphic position calibrated using foraminifera microfauna. This type of deposits with gypsum crystals or clay with gypsum was found in Smardzowice, Imielin, Lędziny 1 boreholes (Silesian Upland) and in the Kraków area (Alexandrowicz 1963, Pilarz 2012). The old question returns: are there one or two Badenian evaporite level in Poland?

Overview of salt tectonics of the Dniepr-Donets Basin, Ukraine

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ABSTRACT

The Ukrainian Dniepr-Donets Basin (DDB) is located in the southeastern part of the East European Craton. It is a late Palaeozoic intracratonic rift basin, with sedimentary thicknesses up to 19 km, displaying the effects of salt tectonics during its entire history of formation, from Late Devonian rifting to the Cenozoic. Hundreds of concordant (anticlines, pillows) and discordant (diapiric) salt structures formed during this time. Salt movement in the DDB began during the Devonian syn-rift phase of basin development and exerted controls on the later distribution of salt structures although the geometry of basement faults is not directly responsible for the regular spacing of salt structures. Post-rift salt movements in the DDB occurred episodically and these were triggered by tectonic events, specifically three extensional events during the Carboniferous - earliest Permian and a compressional event at the end of the Cretaceous. Most overburden deformation related to salt movements is ductile regardless of sedimentary bulk lithology and degree of diagenesis, while the deformation of sedimentary cover in areas where salt is absent is mainly brittle. This implies that the presence of salt changes the predominant mode of deformation of overlying sedimentary rocks. Episodes of salt movement lasted longer than the periods of active tectonics that initiated them. Buoyancy, erosion, and differential loading all played a role in driving halokinesis once tectonic forces had pushed the salt-overburden system into disequilibrium; among these factors, erosion of overburden above growing salt structures acted as a key self-renewing force for development of salt diapirs. Very high sedimentation rates (related to high post-rift tectonic subsidence rates), particularly during the Carboniferous, were able to bury salt diapirs and to load salt bodies such that buoyancy, erosion, and differential loading forces eventually became insufficient to continue driving salt diapirism—until the system was perturbed by an ensuing tectonic event. In contrast, some salt anticlines and diapirs developed continuously during the entire Mesozoic because of much-reduced tectonic subsidence rates (and sedimentation supply) during this time. However, a lower Permian salt series and salt overhangs of buried diapirs played an important role in preventing overburden piercing (and fracturing) during the Mesozoic and, specifically, during the Late Cretaceous salt diapirism phase.