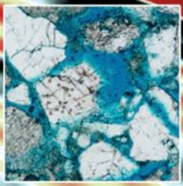
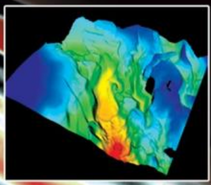
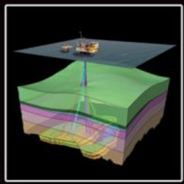

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Abstract Book

Geoscience driving the North Africa and Eastern Mediterranean Energy Hub

31st January – 1st February 2024
Hybrid Event -The Geological Society, Burlington House, Piccadilly London & Virtual

North Africa and the Eastern Mediterranean area is posed to be a critical global energy hub for the 21st Century. Unlocking oil and gas resources, developing CCS and new renewable energies such as offshore wind, hydrogen/helium, geothermal, and associated critical resources. But this is all dependent on improved understanding of the geology, which requires advances at various scales, from regional basin models to focused studies at the pore scale, to challenge long standing paradigms and develop new play concepts.

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Sessions:

1: Regional geology

2. Geochronology and Regional Unconformities

3. Petroleum systems of North Africa an Eastern Mediterranean

4. North Africa and Eastern Mediterranean Case Studies

5. The Messinian Salinity Crisis

6. Nile Delta Clastic Play

7. The Energy Transition in North Africa and Eastern Mediterranean

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Geoscience Driving the North Africa and Eastern Mediterranean Energy Hub
31st January – 1st February 2024

Hybrid Conference, The Geological Society and Zoom, BST

Provisional Programme

Day One	
08.30	**Registration**
08.50	**Welcome**
	Session One: Regional Setting
09.00	**KEYNOTE: Gas Exploration in the East Med: the coming crossroads** Lorenzo Meciani, *ENI*
09.40	**The Geological History of the Eastern Mediterranean: Some Insights from Exploration for Hydrocarbons** Lucien Montadert, *BEICIP-FRANLAB*
10.05	**Eastern Mediterranean area: new insights to support regional knowledge and hydrocarbon exploration in emerging plays** Luigi Gugliotti, *ENI*
10.30	**The Paleotectonic and Paleogeographic History of North Africa since the Permian** Duncan Macgregor, *Macgeology*
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	Session Two: Geochronology and Regional Unconformities
11.30	**KEYNOTE: Source-to sink implications of low-T geochronology: the geology of missing sections** Giovanni Bertotti, *NARG/TuDelft*
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14.10	**Regional Context and Screening of the Northern Algeria Geothermal Play** Duncan Macgregor, *Macgeology*
14.35	**Screening in North Africa and the Eastern Mediterranean: Adapting Hydrocarbon Workflows to Enable Efficient Screening of Carbon Storage Fairways** Craig Lang, *Landmark-Halliburton*
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15.30	**Panel Discussion: The Future of North Africa and Eastern Mediterranean as Energy Hub** Opening and Chair: Andrew Latham, *WoodMac* Graeme Bagley, *Westwood Energy* Mahmoud Khattab, *EGAS* Lorenzo Meciani, *ENI* Yolanda Spisto, *ExxonMobil*
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Posters
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Mediterranean paleooceanography: Facies analysis and foraminifera assemblages of the Cyrenaican Miocene successions, NE Libya. Hamzah Allafi, *Newcastle University*
Architecture and kinematics of the Talemzane and Nefusha Arches, North Africa: a review Rémi Charton, *Delft University of Technology*
Evolution of Mesozoic source-to-sink systems constrained by landscape evolution modelling and time-temperature modelling: pilot study in the Anti-Atlas of Morocco. Rémi Charton, *Delft University of Technology*
Legacy scientific ocean drilling data suggest that subsurface heat and salts cause exceptionally limited methane hydrate stability in the Mediterranean Basin Angelo Camerlenghi, *OGS National Institute of oceanography and applied geophysics, Trieste*
Geometry and kinematics of the active structures along the Latakia Ridge (Cyprus Arc) Michelle Vattovaz, *University of Trieste*
Recycling energy industry data to find new water resources. Marina Flores, *University of Oxford*

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ORAL ABSTRACTS
(In Programme Order)

Session One: Regional Setting

KEYNOTE – Lorenzo Meciani, ENI

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The East Mediterranean basin is a key regional gas producer, fulfilling the domestic gas demands of the largest economies of the region and with an intermittent LNG export contribution to the European market.

The relevance of the basin has been progressively magnified in the past years by several factors:

1. the giant/supergiant discoveries in 2009-15 (Tamar, Leviathan, Zohr), that have more than doubled the volumes discovered in the basin and brought the East Med basin to a different dimension;
2. the recent market requirements to redirect energy needs toward advantaged, lower GHG emission hydrocarbons;
3. the re-emergence of the energy security element in the policies of most governments.

Exploration for additional resources remains an important element of the future of the basin, even if not all the discoveries have been yet fully sanctioned for development.

Most major energy companies are today present in the basin with exploration acreage (Eni, Exxon, Bp, Total, Chevron) and the basin has remained among the most active globally in exploration in the past years, even after the recent oil price crises and Covid19 pandemic.

The basin has had a multi-phase exploration history, with a series of rejuvenations that have revived the exploration success after the area was ruled out for exploration several times (Lottaroli & Meciani, 2022). Such rejuvenations were due to both geological and geopolitical/commercial changes: the discovery of new plays (e.g. the Plio-Pleistocene in the late 90ies, the Mesozoic carbonates in 2015), the market conditions changes (more appetite for gas exploration) and the progressive opening of the relationship between Israel and neighboring countries.

The future of the basin will be dictated by the combination of the directions the basin will take in two crossroads: one is geological and one is geopolitical/commercial.

The Geological crossroad refers to the remaining exploration potential of the basin. How much undiscovered resources the basin holds? There is no easy answer to this issue because the complex, multi-phase exploration history makes difficult the use of simple geostatistical approaches, whose results could be misled by the basin emerging creaming curve. The deep offshore (beyond 1000 m WD) is the area less explored and the area where the largest discoveries have been made; the large Herodotus basin is virtually undrilled, even if concerns on source rock occurrence and effective reservoir presence currently limits the prospectivity perception.

The Geopolitical/Commercial crossroad: will the basin ever become a fully integrated market, with a pipeline network allowing to fully exploit the exploration potential of all sectors of the basin, or will it remain as it is now, with scant bilateral connection? An open market basin will further encourage exploration, allowing operators to act with higher confidence of a rapid commercial destination of the discovered resources.

In the past 15 years the East Med basin has been revived both by new geological new ideas and by market openings.

Will history repeat itself, on a larger scale?

References cited:

F. Lottaroli and L. Meciani (2022). The rejuvenation of hydrocarbon exploration in the Eastern Mediterranean. P 44/petgeo2021-018 | Vol. 28 | 2022 |

petgeo2021-018

The Geological History of the Eastern Mediterranean: Some Insights from Exploration for Hydrocarbons

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Offshore Exploration for Hydrocarbons in the Eastern Mediterranean needed intensive 2D and 3D seismic reflection data acquisition for plays and prospects definition. At another scale, it contributed to a better understanding of the E. Mediterranean geological history particularly for the Cenozoic, as illustrated in this presentation.

A major novelty was the recognition that the formation of the E. Mediterranean Mesozoic NeoTethys was not resulting from the northward motion of a Taurus Block detached from Africa along a Levant Transform Margin. On the contrary, N. Africa was a Transform Margin shaped by SW-NE transform faults, while the Levant was a Passive Margin. It is in accordance with the left-lateral motion of Eurasia relative to Africa during the Jurassic-E. Cretaceous. It explains the detachment of the Eratosthenes Continental Block (ECB) from Arabia and the formation of the rifted Levant Basin and Herodotus Basin. The main rifting phase ceased in the Bajocian in the Levant margin as observed in other parts of the NeoTethys with a possible event in the Early Cretaceous.

The structure of the ECB is now better known but with still stratigraphic and structural uncertainties. Linked to Rift tectonics, tilted faulted blocks are observed, covered by shallow-water Mesozoic and Miocene carbonate platforms separated by drowning events. Major deformations occurred at the Early-Middle Miocene and since the Latest Miocene.

The regional tectonic pattern changed in the Late Cretaceous with the changes in plates motion and the convergence of Africa and Eurasia. It resulted in the formation along a subduction zone, of the Cyprus Arc, a south-vergent thrusted belt of ophiolites and Mesozoic sediments sealed by Maastrichtian sediments. It runs continuously from Northern Arabia to Antalya (Turkey) through the Cyprus Island with far effects southward with inversion of the Palmyre Graben System. Marine surveys show that subduction continued during the Paleogene with an accretionary prism only preserved in front of the NE Cyprus Arc offshore Lebanon.

Major changes occurred since the Miocene linked to the separation of Arabia from Africa and its northward motion: 1- A SE-NW oriented strong shortening event in the Burdigalian, which deformed the Levant Basin and the ECB. 2- The change along the Levant Margin to a strike-slip regime with the individualization of a Block west of the Dead Sea Transform Fault, bounded by a shear Zone along its western side. 3- The westward escape of the Anatolian Block in the Latest Miocene and formation of a new strike-slip Cyprus Arc boundary (The Larnaka Ridge) in the NE, cutting through the previous compressional structures. 4- In the Levant Basin, the formation of a unique set of SE-NW oriented compaction faults affecting mostly the Oligo-Miocene sediments with transition to typical polygonal faults in the NE.

Eastern Mediterranean area: new insights to support regional knowledge and hydrocarbon exploration in emerging plays

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The complex geological architecture of the East Mediterranean area is the result of regional tectonics evolution from oceanic opening to continental plate convergence and collision involving Arabian, Eurasian and African Plates. The area includes various domains: the Nile Delta to the south, the Cyprus Arc to the north, the Levantine Basin to the east and the Herodotus Basin to the west. In the central part the Eratosthenes High stands out, probably as a remnant of thinned continental crust.

The prolific hydrocarbon area hosts a heterogeneous system of plays with different ages and geological context. They have been explored since the 1950's and are still providing excellent discoveries in both mature and innovative situations. Eni, being one of the active players in the area pursues its exploration activities opening new plays, rejuvenating consolidated concepts, and exporting them outside the original areas.

The Tertiary clastic plays of deltaic to deep turbidite systems were the traditional exploration targets in the Nile Delta, later pursued successfully in the Levantine Basin with the discoveries in Israel offshore. More recently the exploration was extended in offshore Lebanon by joint effort of Eni and TotalEnergies. The exploration was supported by integration of various disciplines: seismic data analysis, sedimentological-structural reconstructions and biogenic gas modelling. Particularly, the distribution of the Oligo-Miocene fairways were reconstructed at a regional scale, by using a large amount of seismic and well data available in Eni internal database. Seismic attribute analysis and sedimentological model contributed to the definition of play maps at regional scale. This improved the geological and exploration assessment of the Tertiary clastic plays in the region with the aim to drive the future exploration focus.

The other main play of the East Med is the Mesozoic shallow water carbonate, successfully tested by Eni with Zohr discovery in 2015. This breakthrough in exploration in East Med, unlocked an exploration potential in a disregarded play bringing to the recent (2018-2022) discoveries of Calypso, Cronos and Zeus. Cyprus, accomplished by Eni with TotalEnergies. The recent wells' results and seismic updated data are of paramount importance to improve the geological understanding of the Eratosthenes High area. They can also be a key point for the comprehension of the evolution of the margins facing the Levantine and Nile Delta Basins. To this regard a cross fertilization process of the matured knowledge and experience in the Eratosthenes High can disclose exploration potential in the whole East Med/Levantine region.

Finally the biogenic gas generation is one of the main element of the petroleum systems of the East Med. It was considered to be marginal until the big discoveries in the East Mediterranean region, where the biggest reserves of biogenic gas in the world (more than 100 Tcf recoverable resources) were found. The biogenic gas is associated to both the Tertiary Clastic and

Mesozoic carbonate plays described above. All the recent data collected during the 2022-2023 drilling campaign contributed to improve the knowledge of the different processes affecting the production of the biogenic gas. In the East Med Eni applied a proprietary modelling tool which takes into account the main factors controlling the generation of biogenic gas. The tool computes the biogenic efficiency conditions for potential biogenic source rock layers and estimates the biogenic gas generated volumes. The application of such methodology resulted to be a powerful tool for the estimation of the biogenic gas potential in different geological contexts both on a regional and a prospect scale.

The Paleotectonic and Paleogeographic History of North Africa since the Permian

Duncan Macgregor, *MacGeology*, duncan@macgeology.co.uk, Colin Reeves, *Earthworks*

We present an update of a series of maps we are preparing illustrating the tectonic, climatic, topographic, erosional and depositional histories of the African Plate since the Permian. Maps have been prepared on 19 geological levels ranging from the Early Permian to Present Day, which are illustrated in this presentation over the region of North Africa. Maps can be viewed on www.africageologicalatlas.com. The reader is requested to view these maps whilst reading this text. Much of the talk will focus on some of the more controversial issues over the region, such as the age of the Eastern Mediterranean, the origin of the 'Austrian event' and the tectonic context of Western Desert rifts, all of which can be best understood in the wide regional context displayed on the maps.

Towards the end of Hercynian movements in the early Permian, shear zones penetrated into the African and Iberian continents. Narrow basins were infilled with marine strata tortuously connected through to Neotethys. Additional non-marine rifts were formed around the close of the Permian in the Maragh Basin and Hameimat Basins and also in the Argana Valley of Morocco. By the Carnian (Late Triassic) Neotethys had propagated into offshore Lebanon. This is evidenced by the outcropping of Late Triassic oceanic basalts in Cyprus and in Turkey. The southern Levantine Basin likely remained in a syn-rift phase. The Late Triassic saw an expansion of the area of Atlas and Newark rifting as well as over offshore Sicily. Rifting was thus initiated over a wide belt from the Levantine Basin to Senegal.

Alkaline flood basalts of latest Triassic age were erupted in Israel and a large unconformity is seen there of Norian to Hettangian age. The available window for the initiation of the Eastern Mediterranean oceanic crust off Egypt seems to be from late Triassic to early Middle Jurassic : a younger date is precluded by stresses created by the opening of the Ligurian Ocean in the Middle Jurassic. Horsts and grabens in the hyperextended Levantine Basin trend NNE-SSW, implying transform movement along the sharp Egyptian margin. Such transform movements could have extended as far as the incipient Azores-Gibraltar transform. However the Menderes-Taurides blocks cannot be moved too far west while holding Apulia in place and the phase of NNE-SSW spreading may thus have been short lived. The intensity of rifting decreased over NW Africa though a second milder pulse is proposed in Morocco. A major magmatic event occurred at the Triassic-Jurassic boundary, the Central Atlantic Magmatic Plume. Evaporites were deposited within tectonically controlled inlets such as the Triassic Basin and incipient Central Atlantic.

The Western Desert may have first rifted around the Pleinsbachian, with a second phase in the Middle Jurassic. The context of these rifts is unclear, but a transtensional model related to the Trans-African Lineament can be speculated upon. The first Central Atlantic oceanic crust is thought to have been emplaced around 190Ma, north of the Blake Spur only. According to AFTA evidence, the Reguibat massif of NW Africa may have commenced a long slow topographic rise, though this is not reflected in any significant supply of coarse clastics to the adjoining margin until the Cretaceous. Carbonate deposition became more widespread in the Jurassic with opposing carbonate platforms now developed on the two Central Atlantic margins.

The whole of the African plate would appear to have been experienced NE-SW stretching in the Early Cretaceous, creating a series of NW-SE dip slip rifts, bounded by E-W trending transforms. A third rift phase was initiated in the Western Desert with an extension into the Hameimat Basin. By the Barremian, rifting may have started to spread from the E-W trending Hameimat Basin to the main NW-SE trending Sirt Basin rifts, though there is poor control on this deep section.

The 'Austrian event' of Aptian age covers a) a widespread uplift and unconformity of late Aptian age on which erosion increases towards the active Libyan rifts, b) extensional faulting in Tunisia and offshore Libya and c) sinistral transpressional structuring along shear zones in eastern Algeria and possibly on the N-S axis of Tunisia. The trend may extend further to the Apulia plate margin, where the first significant 'Eo-Alpine' compressions are occurring. Bodin et al

(2010) splits the 'Austrian' into two events in the Late Aptian and Middle Albian and correlates these to unconformities in the onshore Sirt and Gulf of Sirt rifts. This suggests that these rifts were associated with a large regional swell. Sea levels rose at this time, creating a transgression through Africa that peaked in the Cenomanian.

At 86Ma (Santonian), the African plate took a sharp turn and started to drift northwards towards Europe. Associated inversion structures are significant in the Western Desert and Israel, while milder effects are seen in the Algerian Atlas. Active extension continued in the NW arm of the Sirt Basin. Wet climates were now established over much of the continent, with arid conditions confined to northwest Africa.

A period of relative quiescence in terms of tectonics, erosion, sedimentation, and climate commenced in the Campanian. This quiescent period was ended by the first period of compression in the Atlas in the Late Eocene, The Iberian plate collided with Europe, creating the 'Pyrenean' event. The degree of compression seems to have been greater in Morocco than in Tunisia. The first of several transpressional events are described along the Sabratah Fault.

The only Sirt rift still active in the Oligocene was the Hon Graben. From this time onwards, an 'unzipping' trend of rifting is observed from the Gulf of Aden to the Afar and north through what is now the Red Sea. The topography of Africa started to undergo changes in the Oligocene, with the commencement of the formation of the 'basin and swell' topography of Africa and the modern river systems associated with this new topography. A global climatic change occurred at the base of the Oligocene. The warm temperate belt extended to cover parts of northern Africa, with a diminishment of the frequency of evaporites.

The Alkapeca set of plates detached from the Iberian Plate around 21Ma. Over a period of only around 3Ma, this new ocean spread, with the Kabylies then colliding with Africa to create the Tellian structural event and nappe, while the Alboran Plate was squeezed westwards between Iberia and Africa, creating the Rif mountain chain and a large olistostrome in the Rharb Basin. Subduction of the Eastern Mediterranean commenced at around 20Ma, following the accretion of Turkish microplates. An associated phase of folding and transform activity occurred in the Levantine Basin. The unzipping trend of rifting in the Red Sea advanced substantially northwards, with a peak of rift activity around 20Ma. At 14Ma, the Dead Sea Transform was created, ending syn-rift conditions in the Gulf of Suez.

Spreading commenced in the Early Pliocene in the southern part of the Red Sea, though the northern part is thought to have remained in a magma-poor hyperextended state. The initiation of the strongest phase of compressional tectonics in the Maghreb may indicate the creation of an accretionary prism along the southern edge of the Algerian ocean. A new northern boundary to the African plate was created through Sicily, splays creating a series of transtensional rifts around Malta. Folding, often associated with wrench movements, also affected the Nile Delta.

Evolution of the African plate continues at Present Day, with collision with southern Turkey approaching as the final sections of the eastern Mediterranean subduct and with a new subduction zone possibly now being established below northern Algeria.

Session Two: Geochronology and Regional Unconformities

KEYNOTE - Giovanni Bertotti, NARG/TuDelft

Source-to sink implications of low-T geochronology: the geology of missing sections

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Stratigraphic gaps, partly coinciding with the "missing sections" of Green et al. (2022), are key elements for the understanding of source-to-sink systems in part geologic eras. We expand here the definition of stratigraphic gaps to outcrops where exposed old rocks have no cover and, therefore, have a missing section which stretches from the age of the rock to the Present. Regional stratigraphic gaps have been identified by stratigraphers and sedimentologist since a long time and, where angular unconformities were not apparent, typically interpreted in a conservative fashion as related to long periods of non-deposition and vertical stability. This has been the case, for example, of the Hercynian unconformities in Morocco and elsewhere, for the Paleozoic and older rocks exposed in NE Brazil.

Low-temperature geochronology has often disrupted these assumptions revealing a much more complex vertical evolution of rocks underlying the unconformity and/or exposed. When sediments in this position were dated, ages younger than the stratigraphic age have been often found documenting a stage of subsidence allowing for the resetting of the chronological system followed by exhumation back to the surface where they have been covered by younger sediments or have remained ever since. Little of these movements had been predicted before low-geochronology measurements. The tectonic and especially the source-to-sink implications of these movements have not always been adequately investigated. In this contribution, we discussing some case studies highlighting the wider implications of stratigraphic gaps..

The origin and implications of the subsidence stage bringing dated samples to depths high enough to allow the resetting of the geochronological clock are often neglected. Downward movements are typically associated with the development of sedimentary basins, important parts of which have been subsequently disrupted by the exhumation experienced by the same rocks. This implies, for instance, that areas considered as source for sediments were initially subsiding and receiving sediments, leading to a different paleogeography interpretation. This is the case of the Meseta of Morocco and of parts of central Tunisia which we present in this talk.

Subsequent exhumation had the first consequence of disrupting the lateral continuity of the sedimentary basin previously developed and therefore confusing paleogeographic and paleosedimentary reconstructions. In addition, exhumation has created temporary topographic relief which could have formed source areas of sediments subsequently dismantled and deactivated. Sediments, however are preserved in the portions of the sedimentary basins which did not experience exhumation. This is the case, for instance, for the Mauritanides in Mauritania and Senegal.

As powerful as low-T geochronology is, it only provides information on vertical movements which are insufficient to determine the geometry and position of the areas experiencing subsidence first and subsequent exhumation; this makes it difficult to extract tectonic models and define correct source-to-sink relations. The detailed analysis of seismic data from areas adjacent to the outcrops or crossing the sampled well offers a unique opportunity to translate vertical movements in regional movements. In seismic lines, rocks coeval with the sampled ones can be followed away from the outcrop and/or the sampled high. This integrated analysis provides constraints and surprises. Examples from central Tunisia will underline this approach.

Acknowledgements

This contribution results from work of the last 15 years with a number of PhDs and colleagues among whom I would like to mention P. Bruna, R. Charton, M. Gouiza, J. Redfern and many others.

Reference

Green, P., Duddy, I., Japsen, P., 2022. Episodic kilometre-scale burial and exhumation and the importance of missing section. Earth-Science Rev. 234, 104226. https://doi.org/10.1016/j.earscirev.2022.104226

Subsurface and surface data combined with low-temperature thermochronology provide a renewed tectono-stratigraphic model for the Southern Chotts- Jeffara basin, Southern Tunisia

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Southern Tunisia host strategic underground resources in Permian and Triassic reservoirs. An accurate tectono-stratigraphic model is key to predict the quality and the distribution of these resources. The area of interest is a prolific hydrocarbon province and includes a substantial amount of 2D seismic data and associated vintage wells. It also includes the only exposure of marine Permian in Northern Africa (Tebaga of Medenine) and various Triassic outcrops. These unique surface data, largely studied by the scientific community, give access to critical tectono-stratigraphic information from the transition between Paleozoic and Mesozoic times. While Southern Tunisia contains large amount of high-quality data, the tectono-stratigraphic framework of this area has always been a matter of discussion amongst geoscientists.

In this study, we focus on the formation and deformation of Permian to Jurassic sedimentary successions deposited in the onshore area south of the Chotts ranges. The basin lying in that area has different name in the literature and we adopt the informal name of the Southern Chotts-Jeffara basin (SCJ basin) in this study. This basin developed after the Variscan unconformity (Carboniferous), during the Tethyan opening and before the onset of the Alpine orogeny. We here address the depocenter evolution, the location of basin closure, the implications for sedimentary source area and we discuss possible tectonic mechanisms shaping the SCJ basin.

The seismic, well and outcrop data together allow to describe the present-day architecture of the basin and to propose relative timing of major events structuring the SCJ basin. We conducted this analysis along two regional cross-sections (i.e., >200km long) oriented N-S and NE-SW and intersecting the first order structural features at high angle. The most apparent feature along the cross-section is the presence of major angular unconformities translating the occurrence of multiple erosional events in the area of interest. These erosions imply the present-day thicknesses is locally significantly lower than the initially deposited ones. To validate this working hypothesis, we described in detail the internal architecture of each sedimentary units observed in the seismic sections. We have then showed the presence of a major Paleozoic culmination structuring the basin until the Triassic. We also identified the onset of the Tebaga of Medenine during the Triassic. Finally, we describe the emplacement of another culmination (named Triassic culmination) diachronous and geographically disconnected from the previously described culminations. The cross-section allowed also to characterize periods of subsidence explaining the major thickness changes observed at regional scale. It is noticeable that fault displacements are minimal at the scale of the area of interest.

We combined this analysis of the primary distribution of sedimentary packages with Low-Temperature Thermochronology (LTT) analyses. These analyses were conducted on samples we collected on Permian and Triassic outcrops from the Jeffara area. To date, our analyses are the first publicly available LTT in Southern Tunisia. They are consequently of crucial importance to constrain the timing and magnitude of vertical movements and to refine the tectono-sedimentary model of the SCJ basin. During the beginning of the Lower Triassic, in the present-day Tebaga of Medenine, the Permian LTT sample was buried at more than 5 km. This burial episode, never quantified before this study, has potentially strong implications for hydrocarbon systems in terms of maturity and therefore could be of primary economic interest for Tunisia. At around 230 Ma, the Tebaga of Medenine developed associated with the onset of a N-S oriented phase of shortening. This phase brought back to the surface sample the Permian LTT sample quantifying the magnitude of exhumation and the amount of subsequently eroded material (estimated more than 3 km). At the same time, the Jeffara plain (toward the East of the Tebaga of Medenine) was subsiding allowing for the deposition of more than 4 km of Triassic sediments. At around 180-170Ma, an exhumation phase affected the NE part of the area of interest giving raise to the local Triassic culmination. This phase allowed the LTT sample collected from the Jebel Rehach to reach the surface after erosion. One of the most critical findings of this study is that both exhumation and subsidence are controlled by regional long wavelength tectonic processes, in which faults play a limited role.

This renewed tectono-stratigraphic model challenges the prevailing one at the Permian to Jurassic interval. The shortening model we propose is of primary importance because it has implications on the distribution of Triassic sands which are reservoir in the SCJ basin and on the prediction of natural fractures that may affect Triassic and Paleozoic reservoirs.

Session Three: Petroleum Systems

Thermogenic and Biogenic Petroleum Systems in the East Mediterranean Basin

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The east Mediterranean Levant Basin has been proven to contain a prolific biogenic petroleum system. Its thermogenic petroleum systems, though not yet proven economically viable, are inferred to be promising based on the thickness of the sedimentary column, and the presence of several oil shows along marginal and onshore wells. A proper assessment of the East Mediterranean basin hydrocarbon resources needs to take both biogenic and thermogenic systems into account. In a frontier basin and/or a frontier play this becomes a challenging task which requires a complete and integrated workflow to address.

In this paper, we will delve into describing the complex and diverse Play and petroleum system types in shallow and deep offshore settings of the East Mediterranean Basin. Play and petroleum system types include biogenic sourced pre and post-Messinian siliciclastic deep-water turbidite systems and Cretaceous carbonate build-ups, to structural deep fault-controlled systems charged by Mesozoic mature thermogenic sources.

Our discussion will focus on identifying the primary factors and characteristics that control the biogenic source rock potential, as well as the efficiency of charge and preservation of biogenic gas towards trap reservoirs. Additionally, we will provide an update on our understanding of the marine and terrestrial Mesozoic source rock potential and the structural deep-fault system connecting both biogenic and thermogenic systems.

Furthermore, we will delve into the geodynamic and tectonic settings of the basin and their influence on the geothermal heat flow history. This history is shaped not only by the thermal properties of the crust and the lithosphere-asthenosphere boundary but also by factors such as the thermal conductivity and heat capacity of basin-fill sediments and their sedimentation rates. Moreover, we will discuss about the impact of heat flow history and sedimentary heating rates, which play a crucial role in controlling the timing of hydrocarbon generation/expulsion from both biogenic and thermogenic sources.

Finally, we will discuss the hydrodynamic system history of the East Mediterranean Basin and its implications for rock dewatering, fluid flow migration, and, consequently, hydrocarbon migration and charge. In particular, we will delve into the impact of the deposition of the low-permeability Messinian evaporites and their influence on thermal and fluid flow transfer at a basin scale.

Defining Kinetics of unsampled source-rocks in East Mediterranean and other basins

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The recent gas discoveries offshore Egypt, Israel and Cyprus are mostly related to a biogenic gas source, from preserved organic matter in favourable conditions (sedimentation rate, geothermal gradient and anoxicity). Several oil prone source-rocks are suspected within the East Mediterranean basins, and most probably responsible for oil and gas/condensate shows in various wells.

3D/4D petroleum system models have been run over the area to evaluate the maturity and HC potential, and require sensitivity analyses to be performed to capture the thermal, the range of maturity and HC compositions to be expected.

We propose a method to narrow the need for sensitivity analysis on HC generation/cracking reactions, based on Residence time (in My) at a given temperature T- with a +-4° C precision.

HC generation and cracking relies mostly on the resolution of one or several parallel or sequential first order kinetic reactions of Arrhenius type.

$$\frac{dXi}{Xi} = -Ai e^{\frac{-Ei}{RT}} dt \quad (1)$$

Where Xi represents the remaining potential of the ith reaction (Xi0 being the initial potential), Ei: activation energy, Ai: Frequency factor, T: Temperature and t: time.

The detailed analysis of the first order Arrhenius reaction shows that the Transformation Ratio of a reaction i can be expressed analytically in the following form:

$$TR_i = \frac{Xi_O - Xi}{Xi_O} = 1 - e^{-A\Delta t e^{\frac{-E}{RT}}} \quad (2)$$

Where Δt is the residence time of the reactant at Temperature T, and the other parameters identical to equation (1).

Conversely, on can derive the Temperature at which an elementary reactant must be put over a certain residence time Δt for starting (TR at 10%) and ending (TR at 90%) .

$$T = \frac{E}{R}\left(\frac{1}{Ln(A\Delta t) - Ln(-Ln(1-TR))}\right) \quad (3)$$

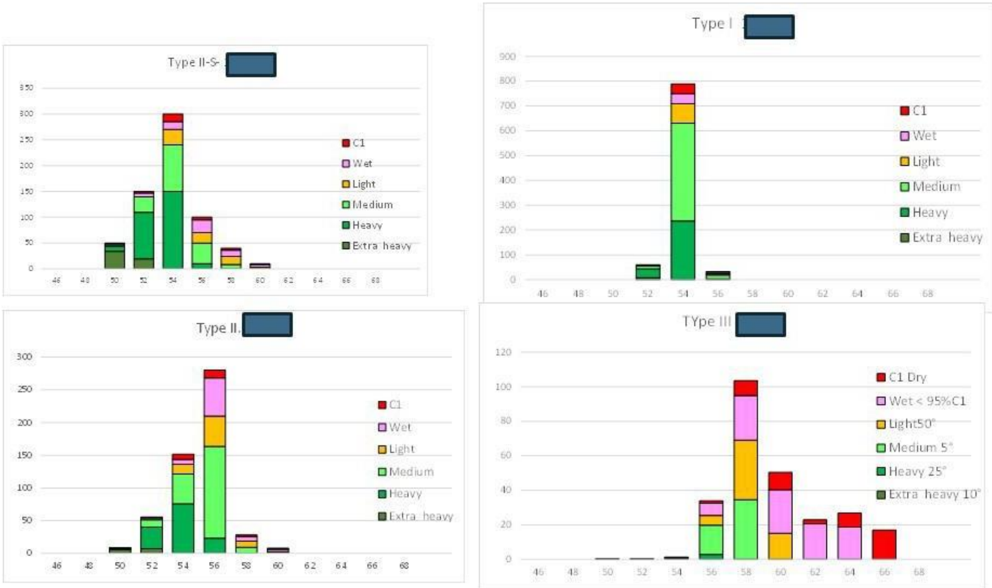
When applied to various source-rock type with conventional set of kinetic parameters, typically E every 2 kcal (E1, E2,..,Ei,.. En) and fixed A (s-1), one can notice that for a given Ei, the reaction of Ei-1 has reached 90% TR when the reaction Ei has just passed 10%TR.

If E and A are fixed for all source-rock types (universal E,A distribution) , one may compare the Xi distribution for different type of Source rocks (Type I, II, II-S, III for instance) submitted to similar residence times and associated T. For this, one can use the published kinetics, compute the T for a given Δt, and find the equivalent Xi for the universal E,A distribution that give the same (or similar +-4°C) temperatures (see figure below).

Interestingly, the various SR type kinetics involve reactions which appear almost completed for Type II-S while type III have barely started. Type I and II have the same main E (54 kcal) , while Type II has potential at lower Energy (therefore T).

This comparison reflects the variable nature of HC fractions present in the organic matters. Longer C-C chains (resins, asphaltenes) with weaker bonds are expected in Type II-S and part of Type II. Homogeneous OM composition is expected for Type I and only stronger C-C bonds (aromatic, saturates) are expected in type III.

The review of secondary cracking reactions in terms of residence time and TR with universal E,A distribution shows also that such reactions may be considered as almost sequential at different temperatures. Considering pseudo HC fractions determined by their density (or API range), one may compare compositional kinetics under the universal E,A .



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In new ventures basins, one can use this approach by estimating first the maximum (+-4°C) temperature reached by the candidate SR and the approximate residence time around that Temperature. One may also convert the individual E,A distribution given by available kinetic measurements to determine the maximum T reached by the sample for a given residence time.

In the case of the deep offshore Levant basin for instance, where geothermal gradients are low, (20°C/km), one can then show that the Temperature reached at 6000 m burial (7000 m to 7500 m subsea) is 110-120°C since 1 or 2 my, and that only Type II or II-S buried at that depth have contributed in the form of heavy , intermediate oils. Near shore Levant, gradients are higher (30-35 °C/ km) and light oil/condensate can be found at 5000 m burial.

Other examples will be discussed in different geological context in terms of age as well as the consequence of the proposed approach on Rock Eval Tmax interpretation.

Early and Late Silurian Oil and Gas Shale Plays of the Chotts and Ghadames Basins of the southern Tunisia Sahara, North Africa.

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In Tunisia Chotts and Ghadames Basins, the Lower and Upper Silurian Fegaguira and Tannezuft Formation comprise organic-rich black mudstones deposited during a major separated anoxic events. They constitute prolific source rocks, having yielded a large volume of oil and gas from conventional reservoirs that reached about 69 MM boe, and 139 MM boe respectively with around of 45 MM boe and 90.5MM boe as recoverable reserves still to be produced respectively.

First investigations on the Lower Silurian Tannezuft 'hot shales' of Ghadames basin (30m thick and organic-rich with average TOC~5.5% in type II organic matter) indicate that they are excellent source rock and display a potential unconventional play with technically recovered gas resources as high as **23TCF**.

For the Upper Silurian 'hot shales' of Fegaguira Formation of the Chotts basin, recent detailed stratigraphic and geochemical assessment allowed the evaluation of its unconventional play potential. The latter is divided into three units (HSII.1, HSII.2 and HSII.3) characterized by gamma-ray values of up to 400° API, organic matter content (up to 17 wt% total organic carbon) and petroleum potential (up to 60 mg HC g−1 rock) with mature Type II marine kerogen.
The first and the second units, which are dominantly organic-rich mudstones, can be compared to the Mississippian Barnett, Miocene Antelope and Cretaceous Tuscaloosa shales of the USA.
Evaluation of the brittleness index shows that the HSII.1 and HSII.2 units are mostly ductile and comparable to tight oil andgas reservoirs, while the third HSII.3 unit, where organic-rich facies are juxtaposed to organic-lean limestone beds with natural fractures (porosity between 3 and 7%), might be considered as hybrid play that may be compared to the Niobrara B Formation of the USA.
Within the shale-oil fairway of the Chotts Basin, the estimated recoverable oil is around **1.3 Bboe.** It is comparable to the recoverable oil estimated volume for the Middle Member of the Bakken in the USA.

Henceforth, the Silurian Tannezuft and Fegaguira 'hot shales' Formations of the Ghadames and Chotts basin of southern Tunisia Sahara, should be considered as important unconventional oil-shale target for Tunisia whose energy balance evaluation clearly shows important steeper increase of the energy deficit since 2010 (Total demand 9.5 Mtep Vs Total supply 4.7 Mtep (ONE-Tunisia).

Session Four: North Africa and Eastern Mediterranean Case Studies

KEYNOTE - Mohamed Hussein

Impact of the Mediterranean Ridge Tectonics on Trapping Regimes of East Mediterranean, Egypt.

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Egypt has developed more than 25 TCF equivalent resources in the onshore and offshore Mediterranean Nile Delta, with track record success, starting from discovery of Abu Madi, moving to many discoveries in the shallow water and then from year 2000 onwards with a series of discoveries in gradually deeper water depths, a paradigm shift was happened to restart a new cycle of exploration. This is exactly what Zohr discovery represents; a change in the exploration pattern of offshore Nile Delta, chasing a completely new play concept with the major companies now focus on the offshore Egypt. The Nile Delta plays (mostly clastic and gas-prone) from the HP/HT Oligocene pre-salt to the DHI-supported Plio-Pleistocene post-salt, were creamed.

Zohr field is believed to be the largest-ever gas discovery in Egypt and the Mediterranean, this field reservoir extends for more than 4,100 m beneath the sea bed, estimated to contain up to 30 trillion cubic feet (Tcf) of recoverable gas reserves. It is worth to indicate that, the tectonic setting of Zohr is not confirmed yet that, due to the Mediterranean rift (Oceanic-continental interplate) or the Mediterranean ridge, which support the existence of another opportunity to find the second Zohr surrounding the Mediterranean ridge. The wide variety of different play types, abundant charge and multi-stored reservoirs make the Mediterranean Sea a striking exploration area.

This work reviews the geological tectonic impact of the Mediterranean ridge on generating different trapping styles in the East Mediterranean of Egypt, study the main tectonic events that affecting on Zohr structure, to allocate where is the possible location for the presence of thick volcanic sequence Paleo-high and the possibility of founding Reefal carbonates “atoll type”, sealed by onlapping lagoonal sediments and Messinian Evaporites and the challenges awaiting the industry in developing what appears to be an emerging new giant fields, using the regional 2D seismic data and the available published work.

Controls on the evolution of the Jurassic Carbonate platform along the Moroccan Atlantic Passive Margin: implications for reservoir development

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An extensive carbonate platform developed along the western Moroccan Atlantic margin in the Jurassic, from the Callovian to Early Kimmeridgian. Carbonate build-ups offer targets for hydrocarbon exploration, some already drilled by wells that have encountered shows, demonstrating an active petroleum system. To-date all have proved non-commercial, with poor reservoir quality being the main issue, although age equivalent carbonates from the conjugate margin are proven reservoir in the Panuke Gas Field of Nova Scotia. Understanding the control that margin evolution has on carbonate facies distribution and subsequent diagenesis is key to targeting optimum reservoir quality, the main risk for future exploration.

The Moroccan Atlantic margin is 2000km long and comprises an underlying rift basin, that developed from the Permian to Late Triassic, followed by passive margin initiated following break-up to form the Atlantic Ocean. Subsidence continues to present day. The rift basins contain thick evaporites that were later mobilised, localy deforming the overburden. Early Jurassic restricted mudstones of the latest syn-rift fill are the likely source rocks for hydrocarbons.

Whilst offshore data (rock samples and log data) from exploration wells that drilled the carbonate are limited, onshore, the Jurassic reefal platform is superbly exposed in the Essaouira-Agadir Basin (EAB). Recent studies of these outcrops have examined the distribution and internal architecture of the carbonate build-ups in order to better understand their evolution and geometry. The diagenetic history of these carbonates has also been assessed, which also offers some insight into potential controls on reservoir development offshore.   This paper uses 3D PSDM seismic and well data from the offshore Lagzira Licence, integrated with data from onshore analogues, to present models for the evolution of the margin and implications for reservoir development and exploration strategy.

The passive margin was not “so passive” in the Jurassic and Cretaceous. Several phases of deformation can be observed that resulted in faulting, folding, tilting and margin collapse, controlling carbonate deposition and potentially influencing reservoir development. Interpretation of the extensive 2D and 3D seismic data reveals a series of large rotational faults that extend approximately north-south across the margin. Detailed mapping indicates successive margin collapse from the middle Jurassic. The sequential failure of the margin resulted in base-level changes and tilting of the platform, drowning the seaward margin of the platform, forcing carbonate facies to backstep landward, developing a new facies belt of build-ups on the remaining stable shallow margin.

Underlying salt movement also influenced surface topography in the Jurassic, and later deformed the basin. This interplay between tectonics, salt diapirism and eustatic sea level influenced deposition of carbonate facies and platform progradation and aggradation through time. A number of major unconformities are mapped from the Late Cretaceous to recent, which removed overburden from the margin (in places the unconformities cut down to the carbonate platform) and are interpreted to have impacted reservoir quality, either through possible karstification or altering fluid movement through the carbonates, impacting the diagenetic history.

The results offer insights into the potential controls on reservoir development to better target exploration activities in order to reduce risk.

Offshore Sirt basin (Gulf of Sirt, Libya): a multidisciplinary approach to the tectono-stratigraphic evolution during Mesozoic.

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Introduction

The Mesozoic tectono-stratigraphic evolution of Gulf of Sirt (offshore Libya) has been analyzed in this integrated work. In the frame of the Eastern Mediterranean hydrocarbon province this area is currently underexplored. The study has been performed by means of detailed 2D seismic interpretation and available well and gravimetric data analysis, which allowed to define the fault network and the main well calibrated seismic horizons. In order to identify and evaluate the depocenter distribution within the study area and through time, isochrone maps have been produced. A further precise calibration of the interpreted faults and depocenters has been performed. The integration of this information was used to investigate the structural evolution of the basin and to build Gross Depositional Environmental maps.

Integrated study

The Gulf of Sirt is part of the Sirt sedimentary basin, included in the segmented SE Mediterranean margin and involved in the evolution of the southern Neotethys. The Gulf of Sirt is characterized by main WNW-ESE to NNW-SSE trending regional normal faults, although secondary NE-SW faults are also recognizable during the earliest rift. The complex basin architecture is related to articulated asymmetric horst and graben structures segmenting the depocentral area. The en-echelon pattern of the main faults suggests a possible right-lateral transtensional regime, marked by synsedimentary activity from Triassic to Turonian. Partial inversion along major faults occurred during the Late Cretaceous to Tertiary Africa-Eurasian convergence, as testified by localized Santonian to Maastrichtian layer folding.

The overall depositional trend is transgressive and characterized by siliciclastic continental-shallow marine depositional systems during Triassic, initiation of shallow marine carbonates sedimentation during Jurassic and the backstepping of the Cretaceous clastic depositional systems coeval with carbonate platforms drowning. The basin margins underwent a differentiated evolution. The Cyrenaica high was characterized by active tectonics during early rifting, followed by minor activity from Jurassic allowing the nucleation of carbonate platforms, which dominated until Late Cretaceous. The Sirt margin was interested by a more continuous tectonic activity up to Coniacian, contributing to a rapid local sea level rise. This led to a larger variability of the depositional systems, with basal continental-marginal marine clastics deepening upward into carbonate platforms and deep water sediments.

Conclusions

The results of this integrated study led to a better understanding of the Mesozoic tectono-sedimentary evolution of the offshore Sirt basin. This could be a relevant contribution for present day and future exploration activities since increasing the geological knowledge of a frontier area is of the uppermost importance to predict the prospectivity of this frontier area.

Acknowledgements

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Keywords: Sirt Basin, Libya, Structural model, Sedimentological model, Platforms, Deep water

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New insights into the late Paleozoic-early Mesozoic tectono-stratigraphic evolution of the Ogaden Basin, Ethiopia

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Available gravity anomaly data together with published 2D seismic profiles and geological transects, and well-log data and information are utilised to assess the tectono-stratigraphic evolution of the intra-cratonic Ogaden Basin in Ethiopia. The gravity anomaly data clearly delineate the extent of the Ogaden Basin by the presence of elongated positive anomalies confined by bounding faults and refine the basin internal architecture. Reservoir petrophysical analyses have been conducted for ten wells within the Ogaden Basin with focus on the late Paleozoic-early Mesozoic Calub, Gumburo, Adigrat and Hamanlei formations. Petrophysical cross-plots show a generalised decrease of porosity against depth within reservoir facies and a corresponding increase of sonic velocities, also revealing aspects of the missing overburden at present time. Detailed line-drawing interpretations were conducted utilising published 2D seismic profiles and depicted in an effective way the depositional characteristics of the individual sedimentary sequences, as well as the imposed structuration. A type-profile crossing the deepest part of the Ogaden Basin depocenter (Bodle Deep) was depth-converted and utilised for 2D structural restoration. The performed analysis indicates that the total crustal horizontal extension was 1600 m and was related to the main extension faults both within the Bodle Deep and towards the Acaba High that bounds the Ogaden Basin. Estimated beta/stretching and thinning factors along the type-profile range between 1.07-1.14 and 0.087-0.12, respectively; indicating comparatively moderate to low extension. Spatial and temporal depositional (pseudo-3D) models that depict the depositional history of the Ogaden Basin from late Permian to present day have been constructed utilising the results of the structural restoration and well-constrained published paleogeographic maps. The performed decompaction analysis and structural restoration of the cumulative Uarandab/Gabredarre/Gorrahei/Mustahil, Hamanlei, Adigrat, the upper and lower transitional zones, Gumburo and Bokh formations show after decompaction and fault restoration a thickening of these formations by 400 m, 450 m, 400 m, 500 m, 600 m, 550 m, and 700 m, respectively. The depositional models show continental settings varying from lacustrine to fluvial and deltaic during the late Permian (272 Ma) to early Jurassic (199 Ma), which led to the deposition of the Bokh, Gumburo, the so-called Transitional zone, and Adigrat formations. The transition from continental to marine depositional settings (due to continental flooding by the Tethys Ocean) during early mid-Jurassic led to the deposition of the Hamanlei, Gabredarre and Gorrahei formations. The study combines and integrates several complementary data and methodologies that bring new insights into the tectono-stratigraphic evolution of the Ogaden Basin in Ethiopia.

KEYNOTE – Joe Killen

High-impact exploration in the Eastern Mediterranean over the past decade

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High-impact* exploration activity and performance in the Eastern Mediterranean since 2014 has been reviewed to place the region in a global context.

41 high-impact exploration wells were drilled in the Eastern Mediterranean in 2014-2023 YTD (25 September 2023), accounting for 5% of the 864 high-impact wells drilled globally in the time period. These 41 wells delivered 6.7bnboe, 98% of which was gas. This accounts for 8% of the total global discovered resource in high-impact wells in 2014-2023 YTD, and 11% of the gas discovered. This was achieved at a 24% commercial success rate, slightly lower than the overall 25% success rate achieved globally.

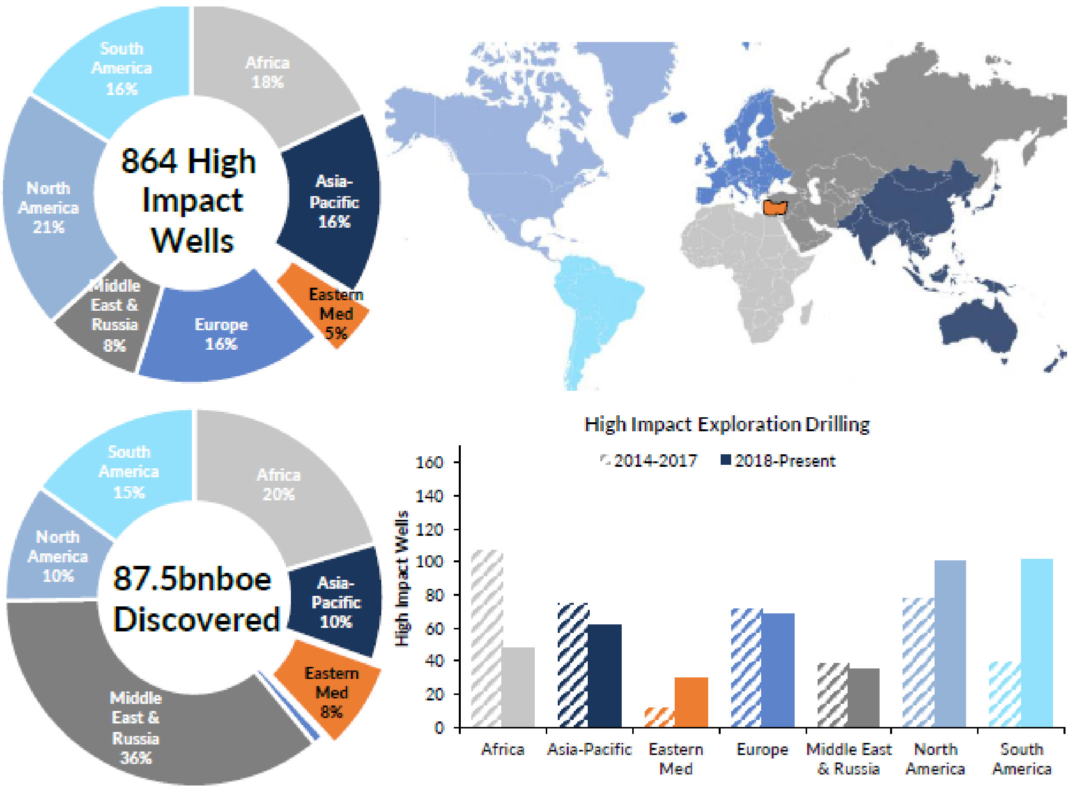

Figure 1 *Global high-impact wells and discovered resource 2014-2023 YTD.*

The most significant new play opened in the Eastern Mediterranean since 2014 is the Cretaceous carbonate play opened by Eni's Zohr discovery in 2015, with resources discovered in the play now ~24tcf. This is the second largest new gas play to open globally since 2014, behind only the Upper Cretaceous play in the MSGBC.

~20 companies currently hold exploration acreage in the region, including all five supermajors. TPAO, Eni, BP, Energean and TotalEnergies were the most active explorers in 2014-2023, all participating in >5 wells. Eni discovered the most resource, followed by ExxonMobil and Qatar Energy.

In the light of the energy transition, cycle times from discovery to production have become increasingly important. Discoveries at Zohr and Tamar outperformed almost all other frontier gas discoveries made since 2006 and have set the standard for the industry to aspire to.

The Eastern Mediterranean is well placed to replace the supply of Russian gas to Europe following war in Ukraine, and take advantage of the gas price premium that is available. The region is experiencing a rejuvenation with ~10% of global high-impact wells planned for 2023 expected to be in the Eastern Mediterranean. These include exploration wells at Orion, Oud, and Khufu, as well as multiple wells in the frontier Herodotus Basin offshore Egypt.

**Westwood defines 'high-impact' as an exploration well testing a >100mmboe prospect (mid-case, recoverable) or any frontier play test.*

Lessons learned from leaky Messinian evaporite seals in the Eastern Mediterranean

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Evaporite seals are widely assumed to be the least risky of all sealing lithologies, with a combination of their ductility, lateral continuity and very low permeability providing an almost ideal set of physical characteristics necessary to hold back substantial hydrocarbon columns. Where pre-salt source rocks have fed post-salt hydrocarbon accumulations it is also often assumed that there are migration pathways around the salt layer or across welds in the salt layer. However, the Eastern Mediterranean area provides a number of cases where the integrity of the thick Messinian evaporite layer has been completely breached by natural hydraulic fracturing, and where hydrocarbons (gas), pore fluid and remobilised sedimentary slurries have transected the overburden to erupt at the surface.

We present a selection of case studies that illustrate the pressure conditions necessary for breaching of the Messinian evaporite seal by hydraulic fracturing. These case studies come primarily from the Levant Basin and the West Nile Slope regions, where contrasts in stratigraphy and structural evolution offer interesting points of comparison. We show that seal breach can be episodic or a one-off process. Where it is episodic, we draw on recent numerical modelling to suggest possible pressure recharge mechanisms and timescales. We discuss the geological conditions leading to each case of seal breach, and the processes that might have been responsible for the extreme overpressures required. Finally, we discuss the wider implications of these case histories for petroleum exploration more generally.

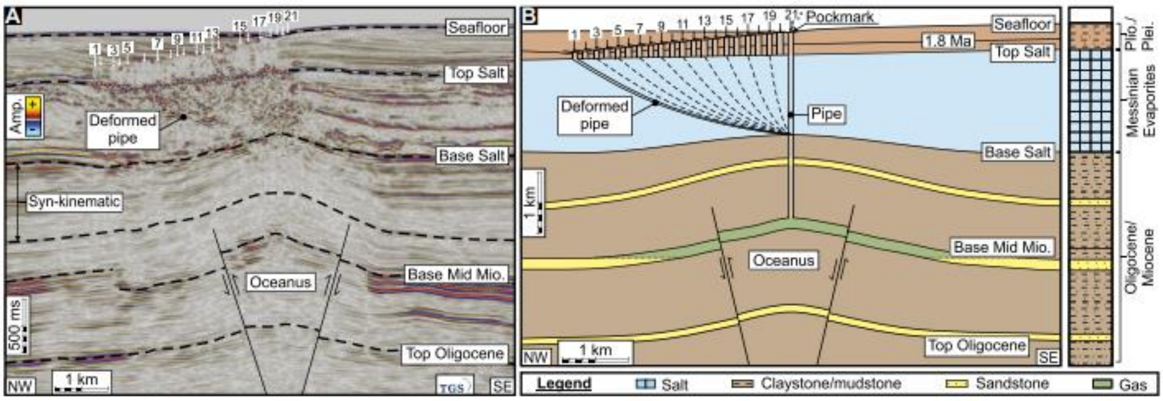

Figure 1: Episodic seal breaching above the Oceanus Structure, Levant Basin, showing deformed fluid escape pipes that formed by hydraulic fracturing of the sealing units by overpressured fluids from Miocene reservoirs. The progressive deformation of these pipes in turn allows us to define the flow geometry of the Messinian evaporite seal unit.

Contrasting Styles of Shale Mobilization, SW Eratosthenes Block, Eastern Mediterranean: Progress towards a Predictive Model.

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Exploration by ExxonMobil and Qatar Energy in Cyprus Block 10, utilizing high-quality 3D and regional 2D seismic reflection data, has identified a diverse variety of piercing and non-piercing shale features. These bodies are observed either (a) directly above Messinian-age salt, (b) as inclined and discontinuous intra-salt bodies or (c) as variable relief structures at the base of the salt. Features with similar external morphologies and salt relationships have been described elsewhere in the Eastern Mediterranean (Kirkham et al. 2022) with formative mechanisms proposed. In offshore Cyprus there is additional complexity associated with the interaction of salt with the architecture and buttress effect of the Eratosthenes continental block (Van Simaeys et al., 2021).

The geophysical expression and character of the various features observed in Block 10 will be described, together with an interpretation of the structural styles and relationship to salt tectonics and shale mobilization. We recognize two distinct shale mobilization domains in southwestern Eratosthenes, separated by the Bolina Arch, the southwestern promontory of the Eratosthenes block. To the east are found non-piercing shale-cored intrusions with a maximum relief in excess of 1500m. To the west and above the Bolina Arch, are observed mega mud canopies representing major breach of the salt. Within this western domain we also observe deformation at the base of the salt, with complex shale-salt interactions.

In 2018 ExxonMobil and Qatar Energy drilled the Delphyne-1 well into a high-relief shale diapir in Cyprus Block 10. A variety of mineralogical, textural, biostratigraphic and physical property measurements were recorded. This dataset, together with ongoing reflection seismic interpretation and potential analog mobile shale characteristics, allows development of models that attempt to explain Tortonian-Serravallian shale buoyancy at the base of the Messinian evaporites. Utilizing a combination of non-equilibrium compaction, over-pressure, mineralogical transitions, biogenic gas generation and regional salt tectonics, has enabled our team to start to develop predictive models for the suite of shale mobilizations features observed in Block 10. We will report on our progress.

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Salt deposition in ultra-deep brine settings by dynamic inflow and evaporation: The Messinian Salinity Crisis example

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Giant salt deposits are known to be associated with natural resources such as hydrocarbons, critical minerals and sometimes hydrogen, all of which will be essential for the energy transition. Therefore, understanding the setting of deposition of giant salt deposits will be important in exploring for natural resource deposits. The Messinian Salinity Crisis (MSC) is the youngest, most studied, and better constrained salt giant and insights of how it formed can be applied to our understanding of the formation of other salt giants. This presentation will showcase the use of integrated mass balance modeling in a dynamic inflow and evaporation (DIE) setting to understand the formation of the MSC evaporite and the changes in pore pressure associated with this unique event.

We propose that when the water-filled accommodation of basins exceeds 1000 m (referred to as an ultra-deep basin), there is the possibility that salt will be deposited in ultra-deep brine (>750 m) settings. We use the term "ultra-deep basin, ultra-deep brine" to differentiate this important class of salt basins and demonstrate that there are natural examples of this class even if the basins have experienced >1000 m base level shifts, like in the MSC.

For the Mediterranean salt basin, we use stochastic back-stripping at four locations, to estimate the paleo-water depth at the onset of the Messinian Salinity Crisis (MSC; 5.96 Ma). The results indicate that the Mediterranean was deeper than 4200 meters in the Ionian basin, and likely as deep as 5000 m at the onset of the MSC. Thus, during the inferred base level drop of 1400-1700 m of stage 2 of the MSC (e.g., Ryan 2008), the deep parts of the basin experienced salt deposition at brine depths of up to 3000 m, well over depths of 1000 m in large parts of the basin.

To understand the timing and seawater flux into the restricted Mediterranean basin required to form the three stages of the MSC, we developed a numerical model of dynamic balance of inflow and evaporation (DIE) into an ultra-deep basin with ellipsoidal cap geometry. The water-filled accommodation of the basin remains constant during the time of the simulation (i.e., no tectonic or thermal subsidence effects were included). Forward modeling balances the mass of water/brine in the basin, dissolved and precipitated salt (mass of solid exceeding saturation of evaporite phases), oxygen and Sr isotopes in each time step of the simulation. The volume of brine and salt are converted to thicknesses at the center of the basin using the ellipsoidal cap geometry. The total depth of the basin at each timestep (i.e., the "c" axis of the ellipsoid) is approximated using a 1D local isostatic calculation by accounting the thickness and density of salt, brine, and air during the evolution of the basin. The fluxes of seawater and freshwater in the basin are iteratively determined based on known boundary conditions and to satisfy geologic observations such as thickness of salt, amount of base level shift and measured Sr isotopes of Messinian deposits.

Numerical DIE modeling for the Messinian Salinity Crisis indicates that to achieve the variability of the salinity between gypsum and carbonate saturation during stage 1, the inflow of Atlantic Seawater in the basin needs to decrease to <33% its pre-Messinian value. A variable inflow of ~9000 km3/yr to ~4000 km^3/yr is a suitable range to replicate the salinity of the Mediterranean and to avoid a significant base level drop during stage 1. During stage 2, the inflow from the Atlantic decreases to <5% of its pre-Messinian value, to as low as ~900 km^3/yr, a significant flux that is larger than the Brahmaputra River. Lower inflow of Atlantic seawater than modelled would result in larger base level drop or complete desiccation of the basin, and longer time to deposit the ~2km salt giant. This model adequately replicates the amount of base level drop (~1700 m), the timing of salt deposition during stage 2 of the salinity crisis (~55-60 k.y.; Roveri et al., 2014; Manzi et al., 2021) the thickness of the salt in the deep part of the basin (~2 km) and the observed Sr isotopic evolution. Finally, for stage 3 the inflow from the Atlantic decreases to zero as the basin becomes fully isolated but the freshwater inflow increased from ~600 km^3/yr to ~1500 km^3/yr, reflecting the inflow of the large paratethyan freshwater into the Mediterranean. These fluxes replicate the salinity variations (carbonate to gypsum) in the Lago Mare stage, the Sr isotope data, and the high frequency local base level fluctuation between ~global seal level and ~500m below global sea level. This base level position is consistent with the spatial distribution of Lago Mare deposits at the margins of the Mediterranean.

In conclusion, the extensive dataset and understanding of the Messinian Salinity Crisis allow us to evaluate the dynamic hydrology of the basin and understand the drivers behind base level shifts and massive salt deposition. Proof of these concepts in the Mediterranean, enables the geoscience community to re-evaluate the model of formation of other giant salt deposits, leading to new play identification and unlocking the natural resources associated with these deposits.

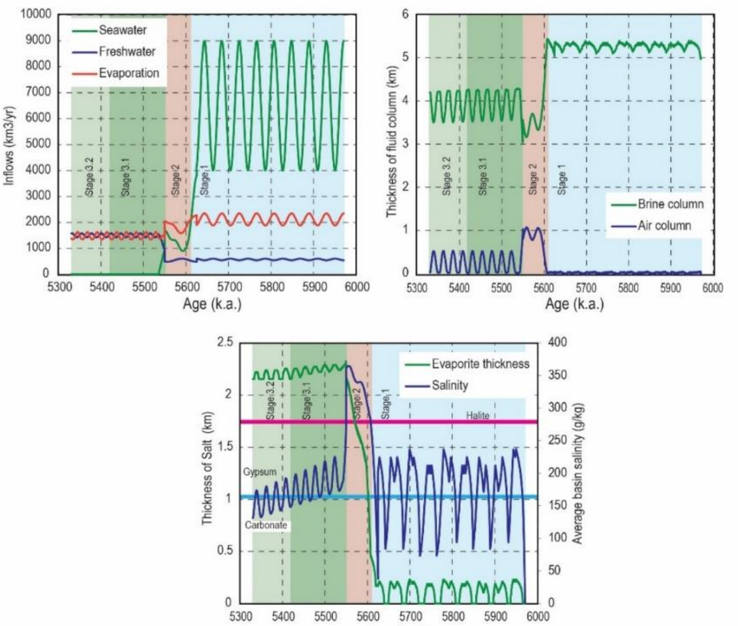

Figure 1. Inputs and results from Dynamic Inflow and Evaporation (DIE) numerical model for the Mediterranean salt basin. These models are consistent with known timing and regional observations of the size of the basins, depth of the basins, salt pinchout positions and thickness/volume of salt deposited in the basins and Sr isotope data. The graphs of brine column, air column and evaporite thickness are at the center of the ellipsoidal cap-shaped basin (deepest location of the basin).

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Session Six: Nile Delta Clastic Play Characterisation

Nile clastic systems: Reducing pre-salt exploration uncertainty through the creation of a post-Messinian reservoir analogue catalogue.

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After decades of successful post-Messinian exploration focused on DHI supported plays, the Nile delta basin is currently undergoing renewed exploration momentum targeting the underexplored pre-Messinian section. The great potential of undiscovered resources within deeper exploration targets have been inhibited by poor seismic imaging that even modern seismic acquisition can struggle to resolve (Particularly at the Exploration scale). While structures can be easier to define, reservoir fairways remain challenging to identify and characterise, which generates large uncertainties and impacts the industry's ability to successfully identify and explore plays.

In order to increase our knowledge of Nile delta derived deep water sediments, years of exploration in the post-Messinian supported by a particularly rich database is a key enabler in unlocking the subsalt. The post-Messinian section benefits from good seismic coverage and imaging, multiple well penetrations and producing fields. Once integrated, this dataset could be used as an analogue to support reservoir characterization of the pre-Messinian clastic system enabling better quantification of the reservoir scenarios used in exploration assessment workflows.

This study is based on the interpretation of 3D seismic amplitudes extractions, spectral decomposition colour blending, and seismic facies calibrated to well data. Utilizing these data, the authors are able to generate a catalogue of elements that characterise the Nile delta deep water systems, including net to gross and geometric trends, seismic facies and insights into systems behaviour.

This paper will share examples from the Plio-Pleistocene which the authors hope can demonstrate useful insights from the newly created shallow sedimentary system analogue catalogue to support deeper sub-salt clastic exploration.

In conclusion, the interpretation of the well constrained post-salt Plio-Pleistocene is an efficient and important use of integrating valuable geologic data to aid the deeper frontier exploration challenges of sub-salt exploration in Egypt.

Reservoir Characterization and Depositional Elements of Atoll Field, Deepwater Turbidite Gas Reservoir, Offshore Mediterranean

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Ahmed Nour, *Reservoir Engineer*, *BP*

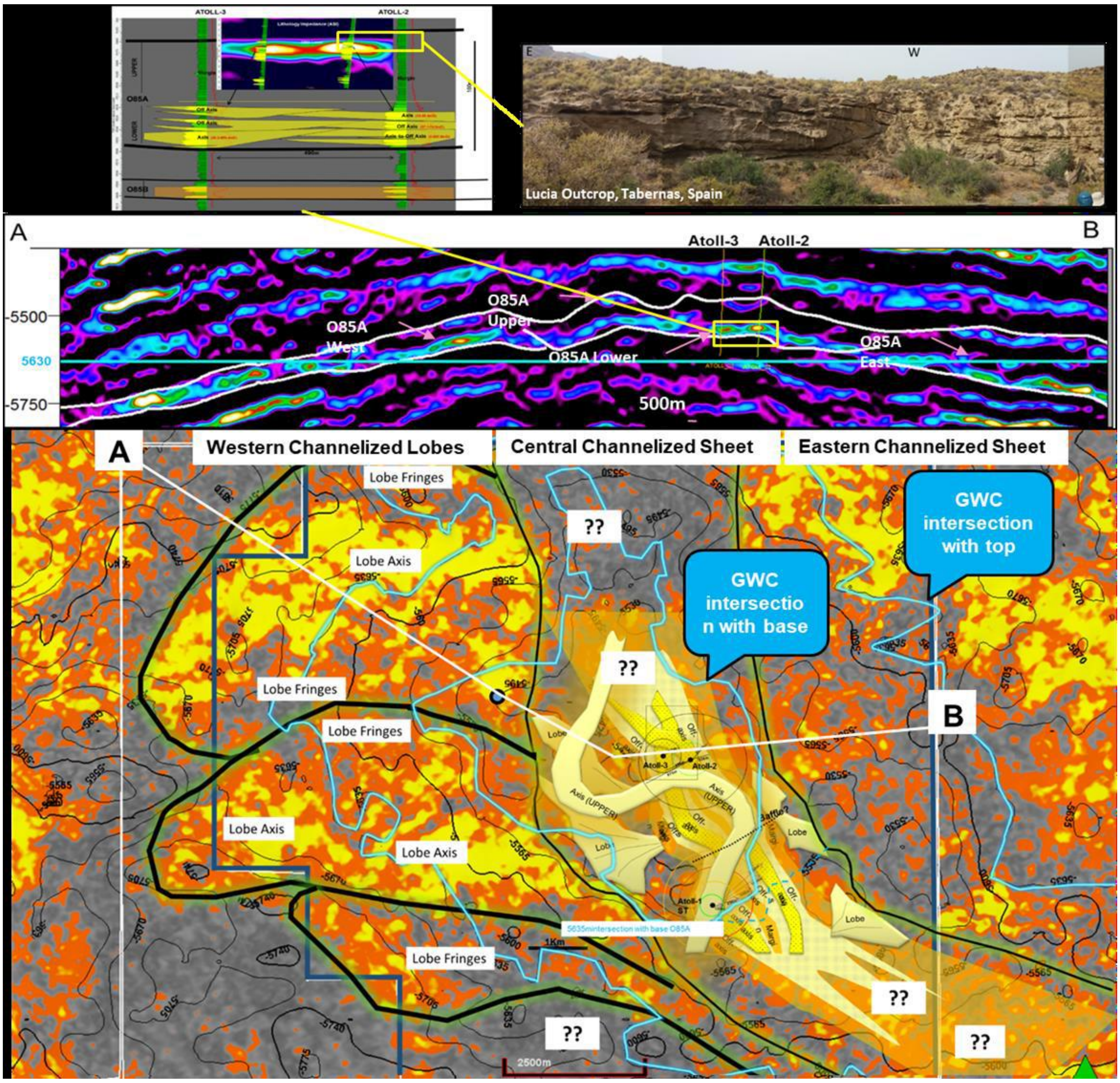
Atoll field is an Upper Oligocene discovery with significant biogenic gas volume located 80km offshore Egypt in the deepwater Mediterranean Sea. The main reservoir of interest is the O85A, aerially split into three zones, the O85A Central, The O85A West and the O85A East.
The reservoir is described as a lower slope unconfined turbidite complex within a four-way structural dip closure. Wells are only clustered in the middle of the O85A Central, penetrating only gas down to the reservoir base.

Seismic data at the time of field discovery and production startup is poor. Significant areas have low seismic amplitude fidelity, due to overburden complexity. Seismic attributes, in the reasonably imaged parts of the field, and well data, indicate channelized reservoir for the O85A Central. The attributes indicate a more lobate architectures for the O85A West. OBN recently acquired to improve the image of the producing field description and assess deeper prospectivity.

Rotary side wall core plugs indicate high degree of heterogeneity in permeability. Averaging permeability using the side wall core plugs is challenging due to sample insufficiency. Pressure build-up data provides excellent calibration to the reservoir k*h. It also indicates deterioration of reservoir quality away from the well, mainly due to reduction of k*h. This is attributed to lateral facies change from channel axis at the wells to channel margins away from the wells.

Surface outcrop examples from the Tabernas basin, SE Spain, Magellanes basin in Southern Chile and the Tanqua basin in South Africa were found useful for this reservoir description.

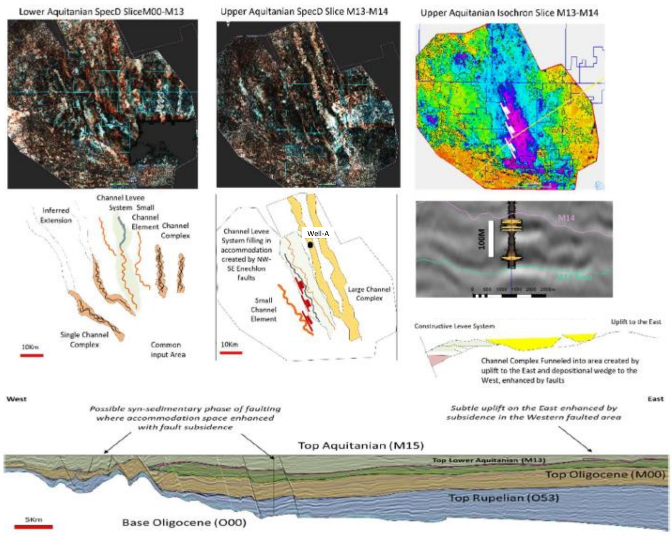
Every piece of information provides important clues to how the reservoir varies. This presentation will provide an example of the Integration of both static and dynamic data, which is key to the reservoir description, especially when the seismic image is poor.



Representative Figure:
Lower Map: Atoll Field Reservoir Depositional Elements Map (RDE).
Upper Cross Section: Colour Inversion seismic cross section across Atoll Field (A-B Line).
Top Left: Zoomed in seismic section at Atoll Field with well log pattern.
Top Right: Lucia Outcrop-Tabernas, Spain.

Spatial and temporal variations of the Pre-Messinian deep water systems offshore Nile Delta using rapid interpretation workflows

The challenge facing recent Exploration and Development activities in the offshore Nile Delta is to define which reservoir systems have a better reservoir developed with high resource density and good deliverability. This study is an effort to shed the light on the structural and depositional influences over the development of the varying reservoir systems on the slopes of the Oligo-Miocene deposits of the Nile Delta area by observing changes in filling history of the area.



The subtle interaction between successive depositional sequences and the response to the ongoing structural modifications through the depositional history resulted in a variety of architectural elements on the slope. Albeit dominated by channel forms; other depositional elements such as splays, channel-levees, mass transport complexes and channelized sheets have been observed with a varying degree of reservoir development and quality. Many of the discovered resources are being found in channel complexes and to a lesser extent in unconfined architectural element.

Although the slopes of the basin had continued to receive sediments through gravity flows and turbidity currents, the systems are hugely variable in size, distribution, and density. Structural growth and major base level drops creating accommodation space for the deep-water systems are found to be the key elements associated with focusing the turbidity currents to produce a good reservoir system while the unfocused multi-point entry into the basin often results in a smaller and narrower systems that are challenging to provide a good gas resource.

The integration of a rapid interpretation workflows over a large merged seismic volume allows for a detailed investigation of the spatial and temporal variations of the depositional pattern on a sub-regional scale which is hugely valuable in focusing the Exploration activities to the best parts of the basin with well-developed deep-water systems.

Session Seven: The Energy Transition in North Africa and Eastern Med; Case Studies

A Unique Geological Framework for Exploration Success: A Holistic Understanding of Eastern Mediterranean

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As a unique region geographically and geologically, the Eastern Mediterranean is rich in dry (biogenic) gas, preserves numerous prolific petroleum systems and has large volumes of underexplored saline aquifers for carbon capture and storage (CCS). As a result, the Eastern Mediterranean will remain a central component of our journey through the energy transition for many decades to come. This diversity of potential subsurface opportunities is driven by the complexity of the region's geological development that incorporates the histories of 3 separate geological plates. Key events in this history include the opening and closing of the Paleo- and Neotethys Ocean, the opening of the Red Sea, the emplacement of an ophiolite, the development of the Nile Delta under different cycles of sea-level change and the desiccation of the region during the Messinian Salinity Crisis (along with many other smaller scale events). All these events have had an impact on the development of petroleum systems in the region. In the following sections, the nature of new opportunities in different settings will be discussed along with the role that developing a regional context for the play has on the understanding of it.

Formed in passive margin settings on epeiric platforms with subtle, differentiated topography, onshore basins like those of the Western Desert are now increasingly mature for exploration. In these settings, consideration is being given to the development of unconventional plays, not least that of the Abu Roash F Member, formed on the distal parts of a transgressive carbonate ramp during an oceanic anoxic event. The context for this deposit provides a more favorable comparison to the Niobara resource plays of the Western USA, which should be used as an analogue to help inform our understanding of this play.

Offshore regions of the Eastern Mediterranean (beyond the Nile Delta) provide significant opportunities for design of new and innovative frontier play concepts. Regional petroleum systems models support the notion that biogenic charge will be extensive across the region with lower heat flows also supporting the likely preservation of reservoir quality at depth. In these settings, integrating the insights from eustatic models and paleoclimatic simulations has helped to de-risk the chance of reservoir occurrence in the distal reaches of these basins and to better understand the controversial provenance of Lower Miocene sandstones in the Levant Basin.

Like many other parts of the world, few studies have focused on the potential character of saline aquifers in the Eastern Mediterranean as targets for CCS. The integrated use of regional depth grids and gross depositional environment maps allows the potential for CCS to be assessed. This regional work reveals potential targets in the Eastern Mediterranean region, though these might have operational challenges, particularly associated with the bathymetry of the area. Furthermore, the integration of these regional models into CO_2 plume modeling applications allows the risks associated with the architecture of sand-bodies to be considered and assessed.

A thorough evaluation of regional geology shows that the future exploration potential of the Eastern Mediterranean for both petroleum and CCS is significant. Insights into exploration potential of the region are best identified using an integrated regional evaluation of its geology that is contextualized by integrating sequence stratigraphic and geodynamic models.

Regional Context and Screening of the Northern Algeria Geothermal Play

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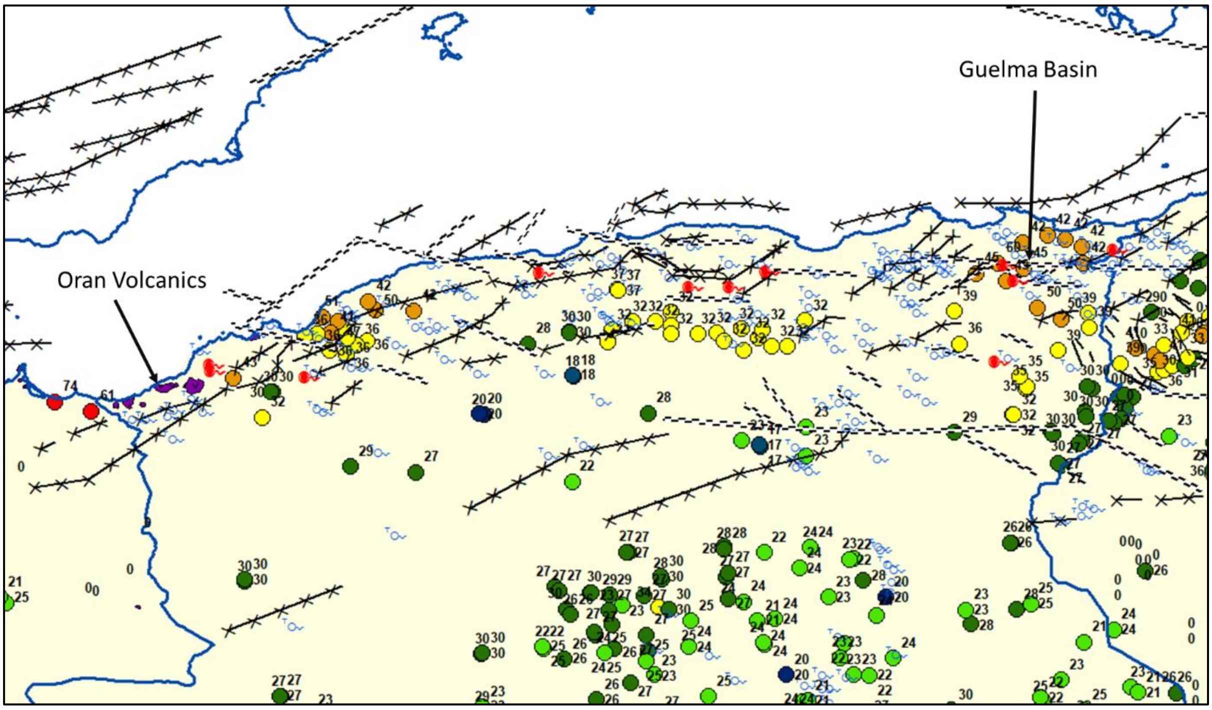
A screening of North Africa based on Recent volcanism, hyperthermal hot springs occurrences, active faulting and geothermal gradient/heat flow has been conducted (supporting maps available on www.africageologicalatlas.com). This rates the region rather poorly on a global scale in terms of the potential for high enthalpy geothermal systems. The highest rated region is that of northern Algeria, within an area of the Tellian Atlas thrust belt that is now being subject to dextral transtension as Africa continues to rotate versus European platelets, creating a number of young pull apart basins. The region forms part of a Miocene to Pleistocene alkaline igneous province that also includes the Canaries and Ahaggar volcanics. The background geothermal gradient is 30-35 deg C/km, with two regional hotspots seen around the Oran volcanics in northwest Algeria and around the Guelta Basin in northeast Algeria, where the geothermal gradient reaches 60 deg C/km, the highest seen in onshore Africa outside of the East African Rift System. The temperature of hot springs, which are numerous, also reaches 98 deg C, the highest measured in North Africa.

The play has been evaluated by Algerian companies and government bodies, resulting in the publication of a Renewable Energy Atlas for the country (Ouali et al, 2019). Much of the work, including PhD research (Bouaicha, 2018) has been on the chemistry of the numerous hyperthermal (>50 deg C) hot springs, enabling the identification of the likely sourcing aquifers. These include Jurassic carbonates in the north-west and Aptian to Cenomanian carbonates in the north-east, both sealed by thick series of flysch. Quartz-based geothermometers indicate reservoir temperatures around 120 deg C, which would be marginal for a binary electric plant. Some emitted gases include CO_2 so higher temperature 'flash' plants would not in any case be environmentally beneficial.

The geothermal waters are meteoric and are circulated through a convective cell which must be driven by an underlying heat source, emerging at the surface largely on faults. This heat source is undoubtedly igneous in the Oran area, where volcanic ages as young as 1.2Ma are observed, In the Guelma area, Helium contents in the waters suggest the presence of a batholith heat source at depth in the Guelma Basin. The hydrogeological models invoked are similar to, though on smaller scale than, the Tuscany system, which is the oldest developed geothermal play in the world. A comparison with developed geothermal plays around the world (Wilmarth and Stimac, 2015) places these Algerian plays into a 'fault based' association, with generally low power density. The play thus looks marginal for large scale electricity generation on the data released to date, with a direct heating application perhaps more applicable, as is the case for the geothermally charged greenhouses developed further south.



Geothermal screening map of northern Algeria. Geothermal gradients in coloured circles, orange=40-60 deg C/km, red tadpoles=hyperthermal hot springs (over 60 deg C), blue tadpoles = other hot springs. lines with crosses= active compressional folds, double dashed lines=active dextral transforms.

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Screening in North Africa and the Eastern Mediterranean: Adapting Hydrocarbon Workflows to Enable Efficient Screening of Carbon Storage Fairways

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As the need to decarbonize is becoming more widely recognised, there has been an increasing expansion of CCS projects, as evidenced by a 44 per cent increase in the million tonnes per annum (Mtpa) of carbon dioxide capacity in CCS projects in the pipeline (Global CCS Institute, 2022 Status Report). There are many challenges involved with CCS technologies, the first of which is identifying where large amounts of CO_2 could be stored? Amongst the prime candidates are depleted hydrocarbon fields and saline aquifers. Saline aquifers are distributed more widely geographically than depleted fields and have a greater capacity, though the density of data associated with saline aquifers is much lower than depleted hydrocarbon fields, meaning that any storage calculations will be significantly more difficult for saline aquifers.

For a saline aquifer to be suitable for CO_2 storage, it requires an impermeable caprock to act as a seal and secure the CO_2. In ideal circumstances, the formations would have been tectonically quiescent since deposition, thus ensuring a higher degree of seal integrity. As well as a suitable reservoir-seal pair, conditions in the subsurface need to meet thresholds for temperature and pressure, allowing for CO_2 to be stored in a supercritical state.

With these factors in mind, we have developed an efficient screening tool that allows for the rapid identification of candidate geological fairways in any given area of interest (Figure 1). The fairway screening utilizes gross depositional environment maps constrained via a combination of public domain data, subsurface models, and geoscience interpretations to map out the extent of the reservoir and overlying seal. Depth grids, generated from public domain data, are used, assuming hydrostatic pressures as a proxy for reservoir pressure. Alongside this, machine learning derived geothermal maps are used to calculate temperatures to determine reservoir conditions for CO_2 supercriticality. A global paleotectonic framework is used to identify significant tectonic episodes that may have impacted seal integrity. These maps are combined in a common chance map workflow. These fairways can then be further constrained by operational considerations, such as reservoir depth and bathymetry. It is then possible to calculate prospective storage resources for both geological and operational fairways (Vangkilde-Pederson et al., 2009). Fairways can then be assessed via a suitability index, considering reservoir, seal and operational factors that could have an impact on the viability of CO_2 storage. This then allows for fairways to be compared and ranked, to high grade stratigraphic intervals for further investigation.

In terms of applying this workflow, we have chosen to investigate North Africa. This is because, along with the Middle East, the region forms one of the largest hydrocarbon-exporting regions in the world and the vast amount, around 85 per cent, of the greenhouse gas emissions in the region come from “energy production, electricity generation, the industrial sector and domestic energy consumption” (Global CCS Institute, 2022). As part of this region, the GCCSI describes North Africa as holding “a major stock of the world’s oil and gas reserves and has always been a key player in the geopolitics of energy. To maintain this position, the region is required to invest in decarbonisation and clean energy technology options.” (Global CCS Institute, 2022). Fortunately, within North Africa, there is experience in CO_2 injection and storage, for example, with the In Salah CCS project in the southern Saharan desert, central Algeria. The In Salah project was a world-pioneering onshore CO_2 capture and storage project, operational between 2004 and 2011, which has built up a wealth of experience highly relevant to CCS projects locally and worldwide (Ringrose et al., 2014).

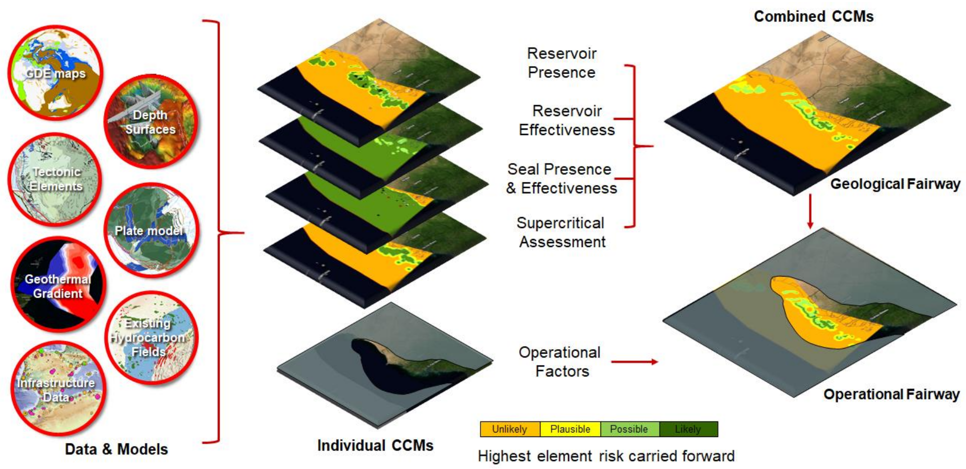

Figure 1: *Generalized workflow for generating CCM maps for CCS Fairways*

Another area of interest with a high level of potential is the north of Egypt. Here, there are already existing natural gas facilities and gas reservoirs that could be tapped to become the location of a CCUS hub. Egypt, alongside Saudi Arabia and the UAE, has announced the establishment of voluntary carbon market initiatives and fully regulated carbon trading exchange and trading schemes. These being established is likely to drive the local and regional carbon market and bolster CCS interest and technologies, alongside other decarbonisation technologies (Global CCS Institute, 2022).

Given the potential within North Africa, we have applied the aforementioned screening workflow to a number of stratigraphic intervals across the region. Triassic fairways throughout Algerian, Tunisian and western Libyan basins in predominantly continental sedimentary systems, such as the Trias Argilo-Gréseux Inférieur (TAGI) Formation, demonstrate good storage potential. Another fairway that shows promise is the Miocene–Pliocene deltaic facies in the Nile Delta Basin, which also indicates a high geological prospective storage resource that is only compromised slightly by the operational complexity of the local bathymetry. As a result, the relative suitability index values for the fairway were encouraging. Shallow marine fairways during the Early–Late Cretaceous of eastern Libya and western Egypt demonstrate some promise, the Sirte Basin rates quite highly for both geological and operational fairways, though slightly more cautionary reservoir and seal indicators are seen to reduce the potential here. Moreover, underdeveloped country policies mean that immediate storage potential is uncertain.

The need for CO_2 storage is not limited to areas with abundant amounts of subsurface data, but as these projects need to be very economical, the case for significant investment in new data gathering for subsurface storage is unclear. Due to the predictive nature of the global models used in the Neftex® solution's screening workflow, it is possible to project away from data constraint and create meaningful comparisons between disparate fairways across a region or even across geological time. Utilising geospatial screening and fairway ranking workflows, it is possible to high grade potential storage units across North Africa, maximizing limited subsurface data to provide an estimate of PSR under geological and operational considerations, as well as possible associated risk factors. These graded fairways can then become the focus of further detailed, local scale studies to build higher-resolution geological models. Looking ahead, we seek to improve upon these newly established toolsets and have identified some methods that we could use to begin more accurately predicting interval thicknesses, and variations across fairways, and try to leverage data to improve our understanding and ranking of reservoir and seal facies. Further considerations to help improve the screening approach and our suitability indications are under investigation, including pressure and salinity alongside further improvements to tectonic impacts and structural complexity.

North Africa and the Eastern Mediterranean can be a future Energy Super Basin

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North Africa and the Eastern Mediterranean are well placed within an oil and gas industry that is increasingly looking for a more sustainable future. The world's need for cleaner energy will change the geography of this industry, increasingly entwining it with renewables and CCS. The upstream of the 2030s and beyond must focus on where its synergies with these decarbonising technologies are strongest.

The best of the traditional big oil and gas basins have the advantaged resources needed to become the energy super basins of the future. But many other traditional basins are disadvantaged, and face being left behind.

This vision of the future offers great opportunity for North Africa and the Eastern Mediterranean. Today, much of the region's oil and gas industry is no longer fully fit for purpose. Not all the basins hold low-carbon advantaged resources. Instead, old fields and infrastructure target the lowest cost barrels. New sustainability and carbon goals are needed to refocus investment.

Most companies' immediate sustainability priority is to reduce scope 1 and 2 emissions. In North Africa, such cuts are best enabled using solar for plentiful clean electricity.

Longer term, the bigger challenge will be to address scope 3 emissions. Hub-scale CCS is the key technology. CCS does not need to be in the same location as oil and gas production, but in practice is unlikely in basins remote from upstream operations. Whilst today's North African CCS industry is in its infancy, the potential for large scale CO_2 storage is clear.

Energy Super Basins are one aspect of a broader industry emphasis on advantaged resources. Advantage spans four key objectives: resilience (low cost), sustainability (low emissions), predictability (low risk) and timeliness (early payback). Multiple overlapping enablers support each objective.

Wood Mackenzie's definition of advantaged resources is based on three of these objectives. Firstly, resilience needs projects to breakeven at oil prices of less than US$40 per barrel of oil equivalent. Secondly, sustainability depends on Scope 1 & 2 emissions intensity of less than 20 $kgCO_2e$/boe. Thirdly, timeliness should achieve payback within 8 years after final investment decision for oil, or within 12 years for gas.

North Africa and the Eastern Mediterranean holds such advantaged resources at scale. Giant gas fields with highly productive clastic and carbonate reservoirs support some of the world's most prolific wells. We see some good options to add advantaged resources via exploration and decarbonisation of existing assets. These discovered and prospective resources can play a role in displacing disadvantaged options elsewhere.

The world will need oil and gas for many decades to come. But there is a huge shortage of advantaged resources to meet expected demand. Worldwide, most commercial undeveloped fields and all the vast global inventory of contingent resources are disadvantaged.

Even including all discovered and prospective options, advantaged resources globally will provide only around 50% of the supply to 2050. Most new supply must come from disadvantaged resources. Ultimately, the energy transition is best served by a reduction in oil and gas demand. Investment in low carbon alternatives can also reduce future dependence on disadvantaged resources.

POSTER ABSTRACTS

Burial and thermal histories in the Crotone Basin (central Mediterranean): the effects of strike-slip tectonics and large mass-transport-complexes

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This talk will address the important role of the Rossano-San Nicola (RSFZ) NW-SE-trending strike-slip fault zone (and a resulting large mass-transport-complex) on the burial and thermal history of the Crotone Basin, a forearc depocenter located inside a subduction system spanning the western and eastern Mediterranean Sea.

High-quality 2D and 3D seismic reflection data (provided by ENI - Italy) and 1D Petroleum System Modelling of exploration borehole and pseudo-wells highlight that the RSFZ has experienced alternating contractional/transpressional and extensional/transtensional tectonics, under a setting of Appenine orogenesis, Tyrrhenian oceanisation and Ionian lithosphere subduction.

This tectonic regime had a profound impact on the economic potential of the Crotone Basin. The emplacement of a large mass-transport-complex derived from tectonic reactivation during the Pliocene permitted source rocks to reach their maximum depth and stay in the gas-generation window until the present day. In the areas surrounding the gas-field, the RSFZ contributed to deepen source-rock intervals and maturity conditions by enhancing local sedimentation rates during the Middle Miocene and the Early Pliocene. This work is important as reveals for the first time the presence of a gas field fully sealed by a large mass-transport complex, ultimately tying the Late Cenozoic history of the Crotone Basin to the geodynamic evolution of the central Mediterranean Sea, namely the Ionian and Tyrrhenian regions. We identify new prospects in the Crotone Basin, and provide a time frame for gas generation and accumulation in southern Italy.

Mediterranean paleooceanography: Facies analysis and foraminifera assemblages of the Cyrenaican Miocene successions, NE Libya.

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Four measured sections of the Miocene Ar-Rajmah Group carbonate rocks in Cyrenaica, north-eastern Libya, were sampled every 0.5 m for sequence stratigraphy. These sections ranged in thickness from 25 to 75 m and covered 94 km. The study so far has involved considerable learning of the microbiocomponents as seen in selected thin sections, this study has been, therefore, present selected representative photomicrographs to illustrate the facies from which will identifying the foraminifera and associated microbiocomponents as well as the petrographic aspects. The initial analysis has revealed that the sizes of foraminifera extended for a wide range, possibly this variation is the result of local and/or regional palaeoenvironmental conditions that prevailed in the Mediterranean region during the Miocene. The sensitivity of foraminifera to subtle environmental changes is well documented, and it will be interesting to reveal what is causing changes in the microfacies and possibly relate them to either local physical geological causes, or global, climatically induced sea-level changes. The effect of seawater chemistry was evident on the pattern of microfacies, and this might be attributed to the volcanic activities. The microbiocomponent size is determined by hydraulic energy conditions, so the energy levels and sorting are a possible influence that will add to the variable controls to be considered. The results showed that a moderately high diversity foraminiferal and echinoid grainstone microfacies that includes the benthonic foraminifera *miliolid* species including the complex larger form *Borelis melo* together with the *rotaliid* forams *Elphidium* spp. (thin walled) and *Rotalia* spp. According to the study so far, it was noted that there was sudden an absence of foraminifera between 7m to 15m, Thus, might be due to the events that happened in the Tethys during the Miocene such as desiccation of the Mediterranean and tectonic events, might be effect by the Indo-Pacific closure.

The changes in petrographic results such as fossil assemblages and lithology have been discussed and showed reflects the range of environmental settings that distinguish the studied Miocene sequence, indicating an overall shallowing-upward trend from open platform to restricted platform and restricted lagoon-salina conditions (Wadi al Qattarah Formation)

Architecture and kinematics of the Talemzane and Nefusha Arches, North Africa: a review

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The Talemzane Arch (TZA) and its eastern counterpart the Nefusah Arch (NFA) are large structural features, only recognised in the subsurface, that extend over 1000km from Algeria to Libya. They follow an approximate E-W trend, sub-parallel to the Saharan Platform northern boundary. Although relatively poorly understood, they appear to represent a complex of regional-scale Precambrian basement-cored anticlines (in TZA referred to as a T-shaped anticlinorium), also involving deformation of Palaeozoic and Mesozoic cover. The folded sedimentary section was truncated during several erosional events during the Carboniferous, Late Permian, Triassic, Jurassic and Early Cretaceous, testifying to its importance as a large and long-lived structure (e.g., Dixon et al., 2010). Palaeozoic basins in the vicinity of the TZA (Ghadames, Oued Mya, Illizi, Timimoun, and Bechar Basins) have been the locus of many systematic investigations (e.g., Underdown and Redfern, 2008), whereas the arches themselves have not been extensively studied and their detailed architecture and structural evolution remain elusive. Likewise, the nature of the connection between the arches and their surroundings is not fully documented.

The TZA and NFA are about 100km wide, with basement located at a depth of c.2-2.5km at the crest of the structure, rapidly increasing to c.4-5km depth away from the anticlinorium core. Both arches are characterised by having Permian sediments recorded on the northern flank, which are absent to the south. To the south, onlapping seismic terminations have been recognised in the Carboniferous, Permian, Triassic, and Jurassic (Bruna et al., 2023; Dixon et al., in preparation). In the TZA, the Precambrian and Palaeozoic rocks are characterised by normal faults, with a typical spacing of c.10-50km. Its northern boundary is defined by reverse faults from the Atlas System (incl. the Chotts Ranges), bounding the arch for several 100s of km. Its eroded crest (a composite erosional surface separating the Palaeozoic and Mesozoic successions) is covered by Triassic and (locally) Jurassic sediments. The NFA also comprises rift-related normal faults compartmentalising the Precambrian and Palaeozoic units on its northern flank. Conversely, its opposite flank appears unaffected by faulting, contrasting with the style of deformation observed in the TZA.

The study is reconstructing the evolution and arch architectures based on detailed mapping (subcrop, depth, and thickness maps), well-correlations, and interpreted seismic lines (using data kindly supplied by our sponsors, compiled within NARG GIS database). The regional cross-sections allow kinematic restoration of the constructed model performed by integrating new Low-Temperature Thermochronology datasets and time-Temperature modelling results (Bruna et al., 2023; Bruna et al., in preparation), with the aim of developing an integrative structural reconstruction of the TZA and NFA evolution from the Ordovician to the

Cretaceous. Our initial results suggest topographic growth in the Carboniferous resulted in a regional topographic high that acted as a barrier to the Permian marine transgression, limited marine deposition further south onto the Saharan Platform. Recognition of compressional structures in the Upper Triassic suggest an enigmatic shortening pulse that affected its northern flank, as well a more recent tilting of the Mesozoic series to the south.

Evolution of Mesozoic source-to-sink systems constrained by landscape evolution modelling and time-temperature modelling: pilot study in the Anti-Atlas of Morocco.

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Mesozoic syn- and early post-rift clastics deposited offshore Morocco on the passive margin were likely sourced from exhumed areas in the adjacent, non-stretched continental crust. Pre-Mesozoic massifs, located onshore Morocco, have been investigated by numerous studies over the last 20 years. Almost all these studies have systematically documented unexpected km-scale Mesozoic exhumation events. 'Unexpected' because these vertical movements occurred during the "passive" stage of Atlantic margin development, and when potential mechanisms from the geological history are difficult to define.

To predict the spatial and temporal distribution of Mesozoic passive margin sands requires an understanding of the paleo-drainage systems, which is controlled by the relative position of exhuming and the subsiding domains. Most of these systems are not preserved or not fully exposed along the western coast of Morocco, resulting in a lack of data about the size, sediment-flux, and entry-point positions.

Estimation of paleo-altimetry, sediment budget, and sediment routing may be derived from processed- based numerical models, commonly referred to as Landscape Evolution Models (LEM). Such modelling allows the testing of the impact of proposed driving tectonic process(es); a major unknown for many past source-to-sink systems, especially in passive margin settings.

We use a two-step workflow: first, the timing, amplitude, and location of the exhuming events at the scale of the margin are constrained based on published time-Temperature modelling; then, the establishment and evolution of the sedimentary systems in the passive margin and its hinterland are modelled with LEM (BADLANDS).

We applied this workflow to the Anti-Atlas; a well-exposed 700km-long Palaeozoic belt located in central Morocco, characterised by a trend oblique to the rifted margin and surrounded by Mesozoic basins. The preliminary results support the control substantial exhumation has on the source location and associated higher discharge and sediment load, as well as the initial drainage pathways and subsequent re-routing of river systems. We can model uplift rates that match the observed stratigraphy, and note these are similar to those typical of tectonic uplift/bulging (c.0.1km/Myr).

Legacy scientific ocean drilling data suggest that subsurface heat and salts cause exceptionally limited methane hydrate stability in the Mediterranean Basin

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The knowledge of the global reservoir of submarine gas hydrates is of great relevance for understanding global climate dynamics, submarine geohazards, and unconventional hydrocarbon energy resources. Methane hydrate formation and preservation is favoured by high pressure and low geothermal gradient, and this leads the reservoir to be hosted mostly in cold passive continental margins. Several studies describe the Mediterranean basin's potential to host a Methane hydrate reservoir. However, in spite of the ample evidence of subsurface hydrocarbons, especially biogenic methane, widespread evidence of gas hydrate either from samples or seismic data is missing.

We modelled the theoretical Mediterranean distribution of methane hydrate stability field below the seafloor and in the water column, using available geological information provided by 44 Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) boreholes, measured geothermal gradients, and thermohaline characteristics of the water masses from CMEMS (Copernicus Marine services). We find that the pervasive presence of high-salinity waters in sediments, coupled with the uniquely warm and salty water column, limits the thickness of the theoretical methane hydrate stability zone in the subsurface and deepens its top surface. Because of the homogeneous characteristics of water masses, the top surface in the Mediterranean Sea lays uniformly from 1163 to 1391 mbsl, much deeper than the oceanic basins where it lays around 300 - 500 mbsl. The theoretical distribution of methane hydrates coincides well with the distribution of shallow, low-permeability Messinian salt deposits, further limiting the formation of pervasive gas hydrate fronts and controlling their distribution due to the prevention of upward hydrocarbon gas migration.

We conclude that the Mediterranean Basin, hosting the youngest salt giant on Earth, is not prone to the widespread formation and preservation of gas hydrates in the subsurface and that the gas hydrate potential of salt-bearing rifted continental margins may be considerably decreased by the presence of subsurface brines. This study was entirely conducted using data (stratigraphy, pore water salinity, and where available downhole temperature measurements) obtained with scientific ocean drilling, thus demonstrating the importance of the legacy data as a source of quality information even decades after their acquisition.

Geometry and kinematics of the active structures along the Latakia Ridge (Cyprus Arc)

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The eastern Mediterranean has been the locus of catastrophic earthquakes and related tsunamis (e.g., M>8, 21 July 365, Creta Earthquake). The primary sources of these seismic events are structures related to the subduction of the Nubian Plate along the Hellenic and Cyprus arcs. Whereas the tectonic tsunami sources along the Hellenic Arc have been extensively studied, a detailed description of the potential tsunamic tectonic sources in the Cyprus Arc still needs to be included. The nature of the collisional zone along the Cyprus Arc is different. In its western sector, an oceanic crust is still subducting the Anatolian Plate. The oceanic crust has been wholly subducted in its eastern sector, and the lower plate is composed of a thinned continental crust. Consequently, the shortening and the seismicity rate are higher in the western sector with respect to the eastern one.

During the last decades, new data derived from extensive hydrocarbon exploration allowed to imagine several structures deforming the sea bottom and influencing the shape of the recent basins in the eastern sector. In this study, we focus on Latakia Ridge: the most prominent tectonic structure in the area. The present-day architecture of this ridge derives from a Meso-Cenozoic convergence, followed by a transpressional phase related to the migration of the Arabian Plate to the north. As a result, today's tectonic structure geometry results from a complex interplay between reverse and strike-slip faults. A re-interpretation of previously published seismic reflection profiles crossing the Latakia Ridge allowed us to reconstruct the geometry of the main active faults and suggest their recent kinematics. Our findings may be crucial to reassessing seismic and tsunami hazards of the eastern sector of the Cyprus Arc.

Recycling energy industry data to find new water resources

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As the global population continues to grow, the demand for freshwater is increasing, while the supply is decreasing due to factors such as climate change and overuse of traditional freshwater sources. Can unconventional, ultra-deep aquifers and offshore fresh groundwater resources help address the water crisis, aided by availability of deep O&G data?

Repurposing O&G data for water resources plays a large role in the identification of unconventional water resources. Recent examples of the use of such data span from seismic and well data interpretation, adapting methods developed from play and prospect generation, data science analysis and machine learning to predict salinity groups relevant for human consumption and industrial uses, and large-scale groundwater modelling of deep coastal and offshore aquifers.

In this presentation, we show examples on how the data from a global well database can be analysed using data analysis, including machine learning, coupled with geospatial data analysis, to identify the global distribution of fresh and saline water aquifers, based on a database which is currently used for O&G projects and for CCUS. To increase the accuracy of the model, we will need greater data volumes across all salinity groups, so further collaboration with O&G industry is instrumental to achieve a full picture of deep groundwater reservoirs in areas of water scarcity. Throughout the project, Earth Sciences Oxford have collaborated with Wood Mackenzie and have exchanged knowledge on workflows and methods. This type of collaboration is increasingly important in the context of the energy transition, showing that the vast datasets held by the O&G industry can be repurposed for novel applications.

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