Eastern Mediterranean – An Emerging Major Petroleum Province

29-30 May 2018

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Introduction from the Convenors

Welcome to the Eastern Mediterranean - An Emerging Major Petroleum Province conference, organised by the Petroleum Group of the Geological Society of London. In this booklet you will find the programme and the abstracts for all of the talks and poster presentations over the two days of the conference. Also, information on the meeting can be found using the Petroleum Group Conference Application, downloadable for free from all app stores.

The organising committee would like to thank the conference sponsors for their support of this event. The Petroleum Group and the Geological Society would not be able to continue to hold events of this scale without continued industry sponsorship.

The aim of this conference is to enhance the technical understanding of the regional geology, key plays and geopolitics of the Eastern Mediterranean.

In recent years the Eastern Mediterranean has witnessed growing interest from international energy companies. Substantial gas reserves have been found in Egypt's Nile Delta Basin and in the Mediterranean coastal areas since 1995. More recently ENI's Zhor supergiant and Calypso giant carbonate discoveries have provided renewed interest in the region. The significant Israeli fields in the southern Levant provide a taste of what may yet be discovered in the northern parts of this basin. Several countries have been announcing licensing rounds in recent years.

The conference will review exploration activity, as well as challenges to a better understanding of the geology in the eastern Mediterranean, including seismic (and other data) acquisition and imaging. Key geological issues for understanding subsurface risk in the area will be addressed, including but not limited to:

- Geodynamic Evolution
- Pre-salt plays including carbonate build-ups
- Source rock distribution and maturity
- The importance of regional seismic and refraction data
- Sediment provenance studies
- Reservoir quality and reservoir characterisation

Our thanks to the Geological Society staff for their help and organisation, particularly Sarah Woodcock for her invaluable assistance. We would like to thank all contributors for their abstracts, presentations and posters. Finally, a sincere thank you to all conference attendees; we hope that you will find the meeting interesting and enjoyable, with plenty of opportunities to exchange ideas and advance understanding of this region.

We look forward to a stimulating and engaging two days.

<u>Convenors and session Chairs</u>

Iain Brown
Mark Osborne
James Gardner

Reference:
Abstracts of 'Eastern Mediterranean – An Emerging Major Petroleum Province', Petroleum Group of the Geological Society, *Burlington House,* 29-30 May 2018

PROGRAMME

CONFERENCE PROGRAMME

Day One	
10.00	**Registration**
	Welcome
	Session One: Structural Framework and Tectonics
10.30	**Keynote: Exploring the Eastern Mediterranean: Defining the Regional Framework for Success** **Owen Sutcliffe, *Halliburton***
11.00	Above Ground Dynamics shaping East Mediterranean Prospects Catherine Hunter, *IHS*
11.20	Twenty Years Exploring the Eastern Mediterranean – Some Critical Q's Dave Peace, *S. D. Exploration*
11.40	**Break**
12.10	The Crustal Structure and Evolution of the Eastern Mediterranean Basin: Insights from new regionally calibrated PSDM reflection seismic data Ken McDermott, *ION E&P*
12.30	Age and structure of the Levant basin, Eastern Mediterranean Uri Schattner, *University of Haifa, Israel*
12.50	Nile Delta – Regional structural framework and Basin Tectono-stratigraphic Evolution Ahmed El Gazzar, *BP Egypt*
13.10	**Lunch**
	Session Two: Petroleum Systems
14.10	**Keynote: Physics and History of Biogenic Gas Systems in the Eastern Mediterranean : The Importance of PVT Conditions** **Duncan Macgregor, *Mac Geology***
14.40	Investigating Potential Charge Mechanisms in the Levantine Basin Using 1D Basin Modelling Michael Treloar, *Halliburton*
15.00	Petroleum Systems of Lebanon: recent advances and future potential Ramadan Ghalayini, *Independent*
15.20	Pore Presure Prediction along the Messinian salt structures usingseismic velocities of the Mersin Bay, Northeastern Mediterranean Sea. S Ayberk Uyanik, *Turkish Petroleum Corporation*
15.40	**Break**
16.10	Egypt's West Mediterranean Sea – An Exploration Opportunity Matthew Pyett, *PGS*
16.20	Seismic indicators of focused fluid flow and cross-evaporitic seepage in the Eastern Mediterranean Claudia Bertoni, *University of Oxford*
16.40	Episodic gas venting from subsalt gas accumulations in the Levant Basin: implications for charge and overpressure in pre-salt plays Joe Cartwright, *University of Oxford*

17.10	A newly discovered giant anticline of early Mesozoic age in the Lavant basin Yehoshua Folkman, *Indepentant Concultant*
17.30	**Finish** **Wine Reception**
18.30	**Optional Hot Fork Buffet (additional charge)**

	Day Two
09.30	**Registration**
	Welcome
	Session Three: Fields and analogues
10.00	**Keynote: The Dynamic Tamar Reservoir - Insights from Five Years of Production** **Jesse Ortega, *Noble Energy Inc***
10.30	Application of fault seal analysis for field development planning of Karish and Tanin gas fields, offshore Israel Yannis Tsiantis, *Energean Oil & Gas*
10.50	The South Disouq Gas Discovery, Onshore Nile Delta, Egypt Stephen Jackson, *SDX Energy Inc.*
11.10	Depositional facies and local distribution of pre-Messinian reservoirs in Southern Crete: A key analogue for the Eastern Mediterranean Basin Tiago M. Alves, *Cardiff University*
11.30	**Break**
12.00	Presence of bottom currents and their effects on the Late Oligocene to Early Miocene deposits around the Cyprus Arc and the Eastern Mediterranean Zhi lin Ng, *Royal Holloway, University of London*
12.20	Discovery of a fluvio-lacustrine system provides new constraints on the Messinian salinity-crisis: Insights from the Levant basin Claudia Bertoni, *University of Oxford*
12.40	Reservoir Characterisation of the Plio-Pleistocene Deep-Marine Sediments of the Nile Delta, Egypt M. Johansson, *Geode-Energy Ltd*
13.00	**Lunch**
	Session Four: Carbonates
14.00	**Keynote: Seismic stratigraphy, evolution and regional context of carbonate platforms on the southern margin of the Eratosthenes High, Eastern Mediterranean** **Trevor Burchette, *Royal Holloway, University of London***
14.30	Isolated Carbonate Platforms of the Mediterranean Region: Geological Features and Hydrocarbon Potential of an Attractive Exploration Target Rusciadelli G, *University of Chieti-Pescara*
14.50	Cretaceous reservoirs of the Eastern Mediterranean: hunting for analogues in the Mediterranean Region Alberto Riva, *GE Plan*
15.10	Deep-water bottom currents deposits from the Lefkara and Pakhna formations (Cyprus): conceptual and economic implications F.J. Hernandez-Molina, *Royal Holloway, University of London*
15.30	**Break**

	Session Five: Regional and Messinian
16.00	The tectonic evolution of the eastern Levant Margin Ramadan Ghalayini, *Exploration consultant*
16.20	Intrasalt structure and strain partitioning in layered evaporites: insights from the Messinian salt in the eastern Mediterranean Sian Evans, *Imperial College London*
16.40	Bypassing of the thick Messinian evaporites in one the most prolific mud volcano provinces on Earth Christopher Kirkham, *University of Oxford*
17.00	**Closing remarks and finish**

Posters

The upper Cretaceous palaeo-slope transition: an integrated calcareous nannofossil and microfacies approach (Ionian Islands, Preapulian Zone, Western Greece) Ioulietta Mikellidou, *University of Athens*
Developing Regional Tectonostratigraphic Models for Hydrocarbon System Evaluation in the External Dinarides and Hellenides Balazs Toro, *CASP*

Oral Presentation Abstracts (Presentation order)

Tuesday 29th May 2018
Session One: Structural Framwork and Tectonics

KEYNOTE: Exploring the Eastern Mediterranean: Defining the Regional Framework for Success

Owen Sutcliffe, Sigrun Stanton, Duncan Hay, James Scotchman, Michael Treloar, and Mike Simmons
Halliburton, 97 Jubilee Avenue, Milton Park, Abingdon OX14 4RW

Outside of the well-established play fairways of the Nile Delta, the offshore Eastern Mediterranean is without question a high-profile emerging frontier for exploration. Two significant plays in this frontier are now documented with the challenge being to map likely play extent. These plays comprise the predominantly Early Miocene turbidites of the Tamar sandstones of the Levant Basin and, more recently, Cretaceous to Miocene carbonate buildups typified by the Zohr discovery. In both cases, the dominant phase of hydrocarbon appears to be dry biogenic gas. This presentation introduces the necessary elements to evaluate these incipient fairways and develop new play concepts, particularly in underexplored areas.

Five primary geological research themes are relevant for reducing exploration risks in this region. They are evaluated using regional geological concepts to aid the delivery of models for exploration success. Each of them is discussed and a framework for their evaluation is provided.

The first theme investigates the provenance of the quartz-prone reservoirs in Early Miocene turbidites of the Levant Basin. These sandstones are extensive, amalgamated into sheet-like bodies, deposited during multiple sequences of sea level fall and, with the exception of the Nile Delta, are flanked to the east by slopes that are essentially out-of-grade. A Paleo-Nile provenance is likely, with regional tectonic episodes on this delta limiting the delivery of sands to the Levant Basin to the Early Miocene. In the Middle Miocene, these clastics could have been diverted into the underexplored Herodotus Basin.

The second theme shows the scale and extent of offshore carbonate play fairways and the ability to predict or identify the occurrence of such carbonate buildups that are comparable with Zohr. Their growth is enhanced where clastic poisoning is limited; in the Miocene (at least), this can be modeled by mapping the basinward diminution of clastics around paleo-highs from seismic sections. Platform carbonates probably developed along the Cretaceous passive margin onto outboard highs that formed during Triassic and Jurassic rifting, so prospective targets are expected to be located along these early Mesozoic structural trends. At Zohr, reservoir quality could have been enhanced by periods of subaerial exposure and subsequent karstification, so larger scale buildups situated on the longest-lived structures that remained elevated near sea level could have better reservoir potential.

The third theme shows the nature and timing of charge, its relationship to trap formation, and the potential for non-dry gas and liquid phases in the resource portfolio. Regional variations in heat flow are poorly identified and are also likely to be influenced by the occurrence of thick Messinian salts. Therefore, the creation of reasoned, regional conditions and multi-scenario burial models is the only way to best evaluate the range of opportunity in these domains.

The fourth and fifth themes are similar and reflect stratigraphic uncertainty around the stratigraphic composition of sub-Miocene plays in the Levant Basin and the stratigraphy of the Herodotus Basin, respectively. These uncertainties are best evaluated through the adoption of a holistic appreciation for regional geological development and a robust model for the broad-scale structural organization.

The future exploration potential of the Eastern Mediterranean is considered significant and insights into exploration are best identified using an integrated regional evaluation of its geology that is delivered by integrating sequence stratigraphic and geodynamic models.

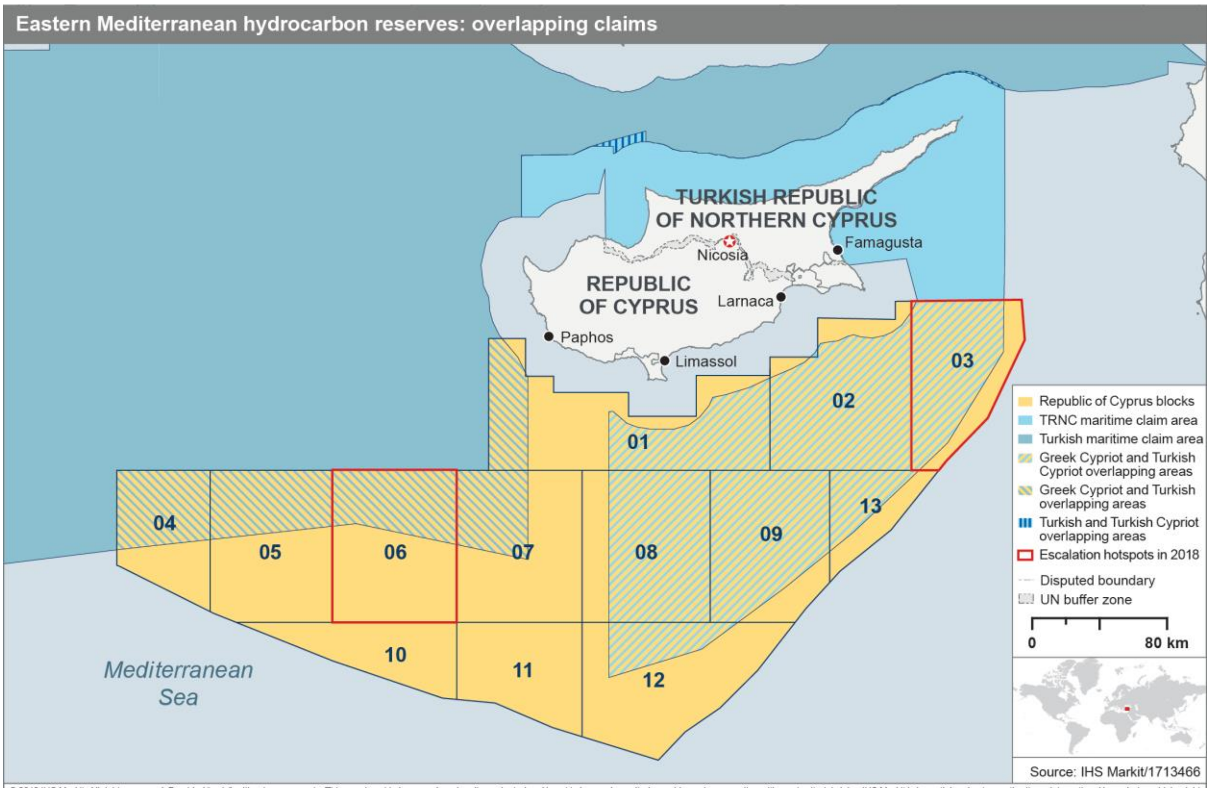
NOTES:

Above-ground dynamics shaping East Mediterranean prospects

Catherine Hunter
IHS

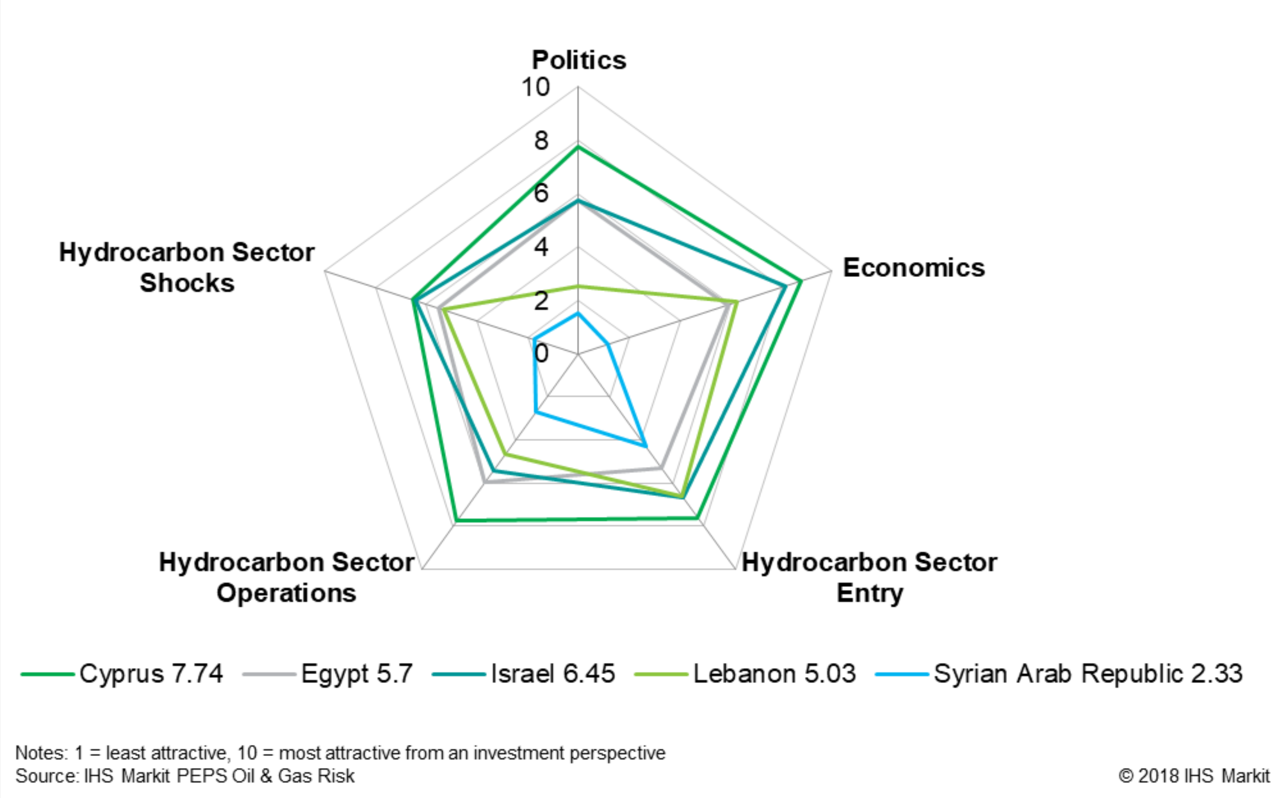
The above-ground dynamics in the East Mediterranean are as complex, if not more so, than the geological setting. They run the gamut from the reform impulses shaking up the competitive environment in an experienced hydrocarbon producer like Egypt, through the challenges associated with defining the state role in the E&P industry in Israel, an early stage producer, and onwards to the uncertainties faced in less experienced "emerging producers and frontiers" countries like Cyprus and Lebanon, where hydrocarbon institutions and legal frameworks are at an earlier stage of evolution.

The difficulties in navigating these regulatory and institutional differences are further complicated by the region's complex legal and geopolitical backdrop, which will determine the pace and focus of hydrocarbon development and have a significant bearing on the monetisation of the, largely dry, gas finds that have dominated the region's recent exploration successes: Gaza's Marine field, discovered at the turn of the millennium and yet to be developed, provides the ultimate cautionary tale here; Are there lessons for Cyprus's Aphrodite and Calypso here?

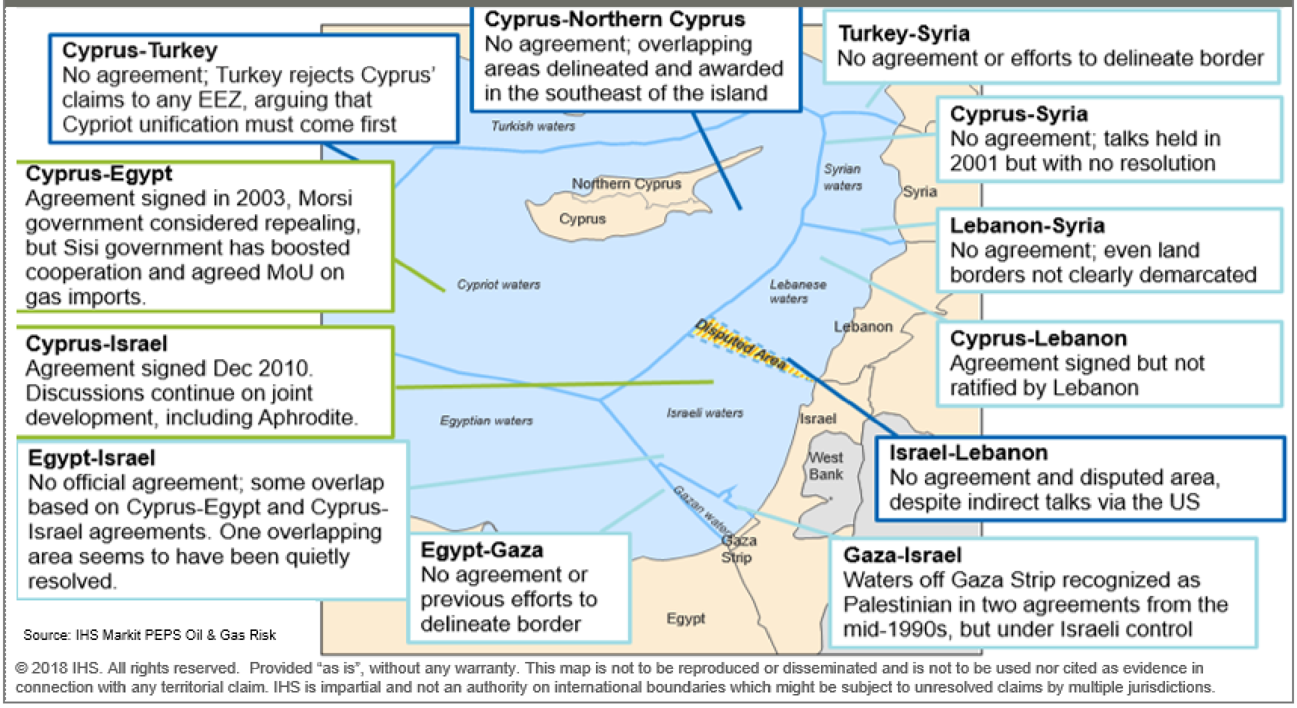


This presentation will examine the above-ground risk profiles of five key East Mediterranean state actors: Egypt, Israel, Lebanon, Cyprus and Syria, using an established methodology, which provides systematic scoring of 21 E&P risk factors, and evaluates how those risks are likely to evolve going forward. It will compare the hydrocarbon institutional and fiscal frameworks of these regional producers using a legal and fiscal framework covering over 200 regimes globally, including those of Egypt, Israel, Syria, Cyprus, the Palestinian territories and Israel. Export risks are also paramount, not just the economics of exports but the politics of such export options, an area that will be another focal point for discussion.

Oil & Gas Risk - Overall above-ground risk rating



Eastern Mediterranean border delineation



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Twenty Years Exploring the Eastern Mediterranean – Some Critical Q's

D G Peace
Exploration Advisor SD Exploration

I would like to help set the scene for this meeting about the East Med, by asking a few critical questions, that we asked ourselves in the early days once we had realized the likely potential of the region. Some of these questions have in part been answered over the last 20 years, but are still highly relevant to todays explorers in the East Med.

Twenty years ago the phrase "exploring the eastern Mediterranean for hydrocarbons", was not one you heard often, and if you did hear it, it was more likely referring to exploring the Nile Delta region.

However, twenty years can be a long time in modern hydrocarbon exploration terms, and as we all know today, the East Med has changed from being viewed as much of a "No Go" area in many ways to being one of the most exciting new gas provinces found in the world, located conveniently close to the ever hungry European markets.

With natural gas reserves currently around 65 t.c.f .or 19 b.c.m., a drilling success ratio that is up with the best of them, and undoubtedly more reserves to find, the scene is set for a very prolific hydrocarbon province to mature.

So what happened to change the early "No Go" perception, and where are we today on answering our critical questions?

Structural History

To start with, the region has a highly unique geological & structural history, which is significantly challenging to unravel. Not only is the area a meeting point of countries and cultures, but also it is an area where large scale geological forces come together in a relatively small surface area. Compression from the north resulting in fabulous over-thrust targets, deep sinking basins along the eastern coast bordered by dramatic limestone sections being rotated by the Dead Sea rift system, huge Nile delta sedimentary systems with long migration paths cascading north out of Egypt, and the whole Levantine basin system bordered to the west by the enigmatic Eratosthenes Sea mount and islands of Cyprus.

While most of the basic structural framework elements such as the Larnaca-Latakia Ridge System, the Levantine basin, the Nile delta and Eratosthenes have been well known for decades, twenty years ago many companies refused to believe there was even a Levantine basin present, let alone the complex set of related basins & mini basins we now know exist.

Excellent advances in both the amount of seismic data now available, and its hugely improved quality are helping drive our understanding of these basic structural questions, while recent 3D data sets are allowing unprecedented finer structural control. It is the finer detail that was not clear then, and it is this finer detail that is needed to move forward. What key elements can't we see yet, what structural controls are still hidden ? & how do the relationships between these elements affect our requirements for source, reservoir, seals & hydrocarbon presence?
Reservoir Presence

Reservoir presence and quality is a key issue that was proven by the early channel sand plays in the Nile delta, but how about more regional sand presence, what are the controls and how far out do they go?. If we evoke reservoir source mainly from the Nile Delta, which many have done, then how far north might it extend and where does it start to fail? How far north has this sand migrated ? has it travelled across the Levantine basin in Israel, how far might it extend into the new plays we see offshore Lebanon? Then what about reservoir sands from the East which are likely to be a very different animal?

Although we clearly have excellent reservoirs present in the Nile delta and southern Levantine basin offshore Israel and Cyprus, reservoir presence in the northern part of the region remains pretty much unproven including the northern Levantine basin, offshore Lebanon and Syria. While we can "predict" the hope for good reservoirs from current seismic and the limited well control available, this northern area remains almost completely undrilled to date and therefore just as unproven.

Then just when everyone is looking the other way, along comes the huge game-changer discovery at Zohr. New reservoir in a virgin area that was looking pretty tough a few years back. Now the biggest new discovery in the region, recently complemented by the Calypso well. So, new rock, new play & how is the reservoir story building there today, how extensive might it be, and what underlying tectonics might be controlling the highs ?

Early seismic in this area was hugely challenging, but remarkable progress in acquisition and processing techniques have helped unravel the unique geological story at Zohr and enable ENI to make this truly stunning discovery

This same poor early seismic suggests there are other structures similar to Zohr in the immediate region, so how far north and west can we chase this new play around the East Med ?

Reservoir Seal

In the early days outside of the Nile Delta, there was of course a lot of speculation that the ultimate seal would be the thick Messinian salt deposits, nothing could get through such a thick pile of salt could it. Well as it turns out, yes it could and does in places.

Early hydrocarbon SAR seep studies showed quite a number of “Seep type” features in the greater East Med region. However when these seep features were later correlated with available seismic, it became clear that the Messinian salt is breached in many places, and such breaches are often linked with gas chimney style features and sometimes small related bright spots. As SAR only works on oil related seeps then these breaches must have an oil component with them, what progress has been made following up on this?

Back to the question of reservoir sealing, what is the current thinking on the shaley Oliogo-Miocene sections that do most of the sealing in the Levantine basin? And how do they differ from the seal at Zohr, which is attributed more to the Messinian Salt than local shales?

Hydrocarbon Source Presence

Prolific gas sources both biogenic and thermogenic are clearly present and widespread, but how does the gas in the Levantine basin at Tamar, Leviathan and Aphrodite compare with the gas at Zohr?, What are the similarities and differences in source, biogenic v thermogenic and mixed source, what is the evolving source story today ?

How close are we to finding commercial oil reserves in the region?. While minor shows of lighter oil had been found in a few of the early wells, and some heavy oil-bitumen type oil shows exist onshore in the east and in the dead Sea. What does modern geo-chemical analysis of recent well data tell us, is there hope for a commercial oil leg, has it all been cooked or what is the real oil potential?

Don't forget the oil seeps found around the entire region…what story are they telling us?

How Much More Could be Found?

Well, twenty years ago, many folks said we were crazy and that we wouldn't find anything; anyone heard that one before? The reality now is that huge gas reserves have been found and self sufficiency is no longer a dream for the countries involved.

Based on early wide spaced regional 2 D seismic we made a lead map of the East Med as far as we were able. Quite a few of those leads have now proven to be commercial gas discoveries, especially in the south of the region, but as you can see there are a lot more to be proven, I think we have only just started and that the region has an excellent future.

A Couple of Other Considerations

As this conference is primarily geological one, I deliberately haven’t talked about the political, commercial and safety aspects of exploring in the East Med, but for anyone considering the region they have to be acutely aware of the issues involved.

Many companies simply could not and cannot explore the region because of other political associations in their portfolio’s or constitutions. This is an ongoing issue complicated hugely by some local politics and sadly, desperate conflict situations.

This is turn, fed early concerns about the safety of any offshore installations that might be put in place. These concerns thankfully seem to be avoided so far, due no doubt to huge diligence and forward planning by all concerned, they should be congratulated and applauded

Exploration success and great new discoveries of course brings different viewpoints, and big success usually means somebody wants a bigger slice of the cake than they first thought when there we no discoveries found. The last 10 years have seen the cost of entry going up and up to the point where it is almost impossible now to participate unless you are a billion dollar corporation. Gone seem to be the days when a creative smallco could explore with the best and make a difference, which personally I find rather sad, given that it was largely due activity by small to medium company's that helped get the East Med started.

So how can we continue to encourage smaller companies to invest their ideas and efforts, while recognising that the bigger companies are of course needed to help exploit, develop and produce discoveries.

So the East Med today is still enigmatic, complex, exciting, challenging, difficult, frustrating and at special times also pretty darned stunning, with a huge future ahead of it.

Its amazing what a difference 20 years can make, here's to the next 20 years.

NOTES:

The Crustal Structure and Evolution of the Eastern Mediterranean Basin: Insights from new regionally calibrated PSDM reflection seismic data

Ken McDermott, Elisabeth Gillbard, Neil Hurst, Paul Bellingham
ION E&P Advisors, 31 Windsor St. Chertsey, KT16 8AT, UK

Many models describing the overall crustal structure of the Eastern Mediterranean Basin (EMB) have been published in recent years. The majority subscribe to the view that the EMB initially formed through NW – SE directed rifting that led to the formation of (probably) a Mesozoic NE – SW trending Neo-Tethyan rifted margin, later overprinted by Cenozoic compressional tectonics. Many of the published models rely on regional gravity modelling combined with sparse refraction seismic data to delineate the crustal structure of the Neo-Tethyan margin. Due to a paucity of high-quality deeply-imaged reflection seismic and the large sediment thickness, these models are largely uncalibrated geologically so the location of the COB and how far to the NW the continental crust extends is relatively unconstrained. As such, consensus on the location of fundamental structural elements (i.e limit of continental crust, LoCC; and limit of oceanic crust, LoOC) has not been reached. As exploration moves farther offshore the need to understand the overall crustal structure is heightened due to the need to calibrate our petroleum systems models and define effective play-types.

In order to address some of this ambiguity, ION acquired the first SPAN profile (long-offset, long record length, 2D reflection seismic data) in the region during the summer of 2015. The profile, designed to answer some of the key geological questions, is 360km long and orientated NW – SE and depth migrated to depth of 40km in order to image the Mesozoic rifted margin. As such, the profile provides a fully trans-crustal image including the entire sediment section and top of basement allowing for a detailed investigation of the crustal structure and geological history to be completed. As far as the authors are aware, these data are the first to successfully image the entire sedimentary and crustal thickness in the EMB, with the majority of publically available reflection seismic datasets not having a sufficient record length to image and correlate top basement.

Through interpretation of these data we demonstrate that the Neo-Tethyan margin offshore the Nile Delta is likely an example of a magma-poor "upper-plate" margin complete with hyper-extended continental crust and a potential region of exhumed partially serpentinised mantle in the distal domain. We show that the sediment pile in the distal domain (above potentially exhumed mantle) is significantly thicker than previously estimated and is up to ~14km thick in the distal Herodotus basin. We show how the crustal structure of the original rifted margin has strongly influenced the present day localisation of compressional strain and the formation of the observed strike-slip faulting and folding of sedimentary strata around the Rosetta fault system as the EMB has progressed through its current compressional phase.

Incorporating our interpretation of the newly acquired SPAN data into IONs ~12,000km of regionally calibrated, newly reprocessed and depth imaged Mediterranean seismic dataset, the complex geological history can be elucidated with significant implications for the evolution of the EMB, allowing for a mega-regional re-evaluation of the crustal structure, the therefore heat-flow and petroleum systems models for the EMB.

NOTES:

Age and structure of the Levant basin, Eastern Mediterranean

Segev Amit[1*], Sass Eytan[2], **Schattner Uri[3]**
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[2]*Institute of Earth Sciences, The Hebrew University of Jerusalem, Jerusalem 91904, Israel*
[3]*Dr. Mosses Strauss Dept. of Marine Geosciences, Charney School of Marine Sciences, University of Haifa, Israel*

Large parts of the Mediterranean were formed during the Mesotethys Ocean opening, and subsequently became land-locked at the midst of the Africa-Eurasia plate convergence. Previous studies widely agree that its easternmost part, the Levant Basin, opened during the Permian to Early Jurassic (PJ) and accordingly explain the architecture of the basin and its margins. However, since the PJ model was suggested in the late 1990's a flood of new evidence came from hydrocarbon exploration, some of which do not fit in with the PJ model, and some remain unexplained. The current research re-examines the old and new evidence from the Levant basin, its margins, the surrounding landmass, the adjacent Eratosthenes Seamount and the Herodotus basin. The integration of data suggests that the Levant Basin formed ~100 Myr later than previously thought, i.e. during the Cretaceous. Its opening was triggered by the 'Levant-Nubia' mantle plume. The plume induced a sequence of wide-spread Ocean Island Basalt volcanism. The resulting crustal updoming and stretching led to the breakup of the Levant landmass since ~141 Ma, and drifting of the Eratosthenes Seamount since ~125 Ma. Back-arc extension shaped the Levant Basin as a hybrid crust comprising continental slivers intervened by oceanic patches. The basin opened during the Long Normal Cretaceous Polarity Chron C34N and therefore it does not show any magnetic lineations. The opening of the Levant basin occurred while the Herodotus basin floor subducted eastward under the Eratosthenes Seamount. The subduction hinge did a roll-back and facilitated the Seamount drifting. The Seamount absorbed additional volcanism while chasing the subduction roll-back and sliding between two Subduction-Transform Edge Propagator (STEP) faults that bounded the stretching Levant back-arc basin. The Turonian-Senonian compression stress regime halted the extension of the Levant Basin, stagnated its hybrid fabric, and prevented the development of a spreading center. The evolutionary scenario suggested here is a game changer for future exploration in the Levant and may serve as a global analog for the formation of marginal seas.

NOTES:

Nile Delta – Regional structural framework and Basin Tectono-stratigraphic Evolution

Ahmed El Gazzar, Tarek Afifi, Gihan El Bakry, Todd Lapinski, Erik Hulm, Mohamed H. Saleh, Tim Bevan
Geologist BP Egypt

From over 20 years of exploration in the eastern Mediterranean, BP has combined a wide array of data into a single integrated framework that synthesizes basin evolution from its formation during Mesozoic Tethyan rifting, through repeated phases of basin closure, to the relatively recent input of the Nile River and the effects of the Messinian event.

The Mesozoic history of the basin comprises an Early Jurassic syn-rift fluvial-deltaic dominated clastic section followed by a Mid-Late Jurassic post-rift carbonate platform. The Early Cretaceous had a renewed entry of clastics input into the northern Egypt basins and deposition of fluvio-marine sediments. This was followed from the Late Cretaceous to Eocene by the deposition of a thick carbonate section (including platform, patch reefs and pelagic sediments) during which the compressional "Syrian Arc" events resulted in inverted anticlines and compressional thrust-cored folds, with local erosion and truncation over structural crests.

During the earliest Oligocene, in response to the Africa doming, the Nile drainage system was established and delivered huge amounts of sediment from the central African hinterland towards northern Egypt and the Mediterranean. Onlap of early Oligocene sediments onto the basin margins and paleo-highs can be interpreted from seismic and thickness maps across the Nile Delta basins. Oligo-Miocene sedimentary fill consists mainly of turbidite slope deposits, channels and basin floor fans, with an overall progradation of the delta system updip throughout the Cenozoic.

These Oligo-Miocene clastic sequences were capped by evaporates that were precipitated during the Messinian Salinity Crisis which occupies deep parts of the basin. The shallow and onshore areas were subject to subaerial exposure, erosion and deposition of clastic sequences via active fluvial systems of the Abu Madi Formation. The Plio/Pliestocene delta and slope deposited following the Early Pliocene flooding event comprises a number of major discoveries in the basin.

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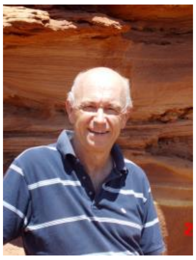
Tuesday 29th May 2018
Session Two: Petroleum Systems

KEYNOTE: Physics and History of Biogenic Gas Systems in the Eastern Mediterranean: The Importance of PVT Conditions



Duncan Macgregor
MacGeology Ltd, Reading, UK

The Eastern Mediterranean now constitutes the largest offshore and non-coal associated biogenic gas system in the world. The high productivity of the system may be related to a number of unusual observations, the main one being that reservoirs are generally older, deeper and hotter than elsewhere, lying close to or beyond the biogenic window that is conventionally thought to end at around 65-70°C.

This investigation attempts to explain these observations and analyse whether conventional models relating to biogenic gas generation require any revision. The development of large fields at or below the limits of the conventional biogenic gas window (e.g. Tamar at 78 °C, Mari B and Zohr estimated to be around 70 °C at their gas-water-contacts) requires either that a temperature extension to the window is developed or that the physics of the system allows earlier filled fields to be buried below the window without significant gas shrinkage or leakage. Biological data elsewhere, particularly from China, suggests that most biogenic gas is generated below 62 °C, hence the focus in this investigation lies on the physics of the systems, particularly PVT (Pressure-Volume-Temperature) conditions. The study relies on rather sporadic data released on some of the deepwater fields from Noble engineering papers and environmental impact studies, though a more substantial database exists on the shallow water fields. No direct data exists on Zohr at this stage, though inferences are made.

The region appears to have a remarkably consistent surface heat flow of around 50 mW/m^2 (Figure 1), though this is translated into a variable geothermal gradient by thermal conductivity variations, particularly related to the presence or absence of thick Messinian salt : the typical geothermal gradient for sections below such salt is around 20-22°C/km. The published PVT data has been used to construct a series of charts determining the variation in reservoir temperature, pressure and Gas Expansion Factor against time (e.g. Figure 2), allowing relationships to be observed with the evolution of key petroleum system elements such as seal compaction and trap formation. While it clear that the gas in the Zohr, Mari B and the Nile Pliocene fields was generated post-Messinian, this seems unlikely to have been the case for the older 'Tamar Sand' fields. The model proposed for these is that the gas pools were filled prior to the Messinian lowstand and then suffered de-pressuring and gas expansion followed by a rapid re-pressuring and compression. A lack of significant subsequent recharge due to the imposition of higher temperatures beyond the biogenic window is speculated to lead to these closures having only a partial gas fill in comparison to apparently higher degrees of fill in the Pliocene fields such as Mari B. The presence of small amounts of condensate and intermediate isotopic compositions in many pools (Figure 3) indicate a degree of mixing with thermogenic gas, particularly in the Nile system, though regional correlations between condensate yields and the isotope values seems to confirm that the deepwater fields are primarily biogenic, confirming the various operators reports.

The Eastern Mediterranean biogenic systems are optimised for the formation of large biogenic gas fields due to a number of favourable factors. Firstly traps of various types (Syrian Arc anticlines, carbonate buildups and sand Injectite mounds) are formed in time for the closures to be filled with gas generated throughout the biogenic temperature window. The deposition of all elements of the petroleum system in already highly pressured deepwater settings ensures that early gas fill at low temperatures is sufficiently compressed to enable gas preservation in traps in non-generative periods. A particularly key aspect here is a trend of flattening of the Gas Expansion Factor (Bg) against increased burial (e.g. Figure 2), which allows biogenic pools to survive burial below the actively generating window without suffering significant shrinkage. Effective seals must also form early, with mudstones sustaining columns of the order of 300m and evaporites over 600m at Zohr : the early pressurisation of the system likely plays a role as well here. These same physical controls are recognised in other recent deepwater biogenic discoveries, for example in Myanmar, and should form the basis for deliberate exploration for biogenic gas in frontier provinces worldwide.

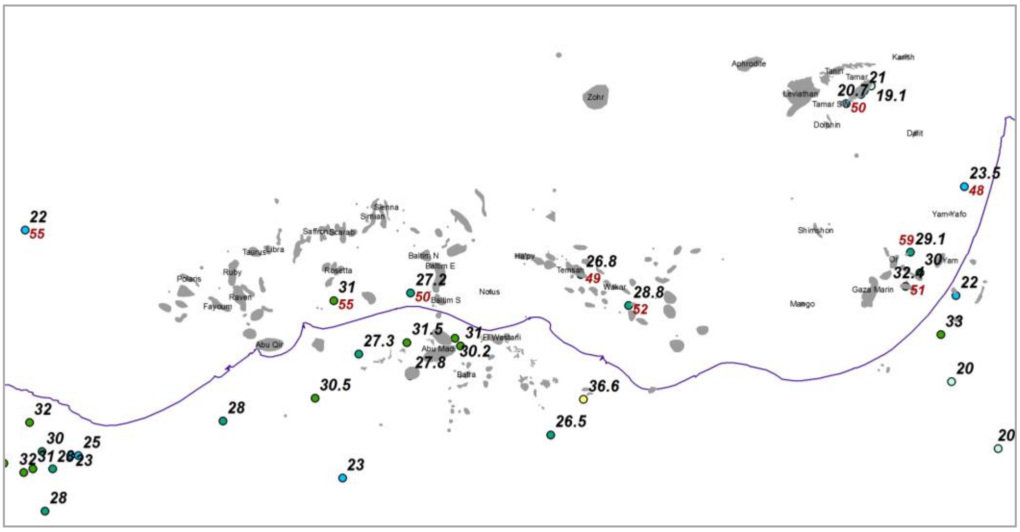


Fig 1 :Reported geothermal gradients (black numbers, degC/km) and estimated heat flows (red, mW/m²).

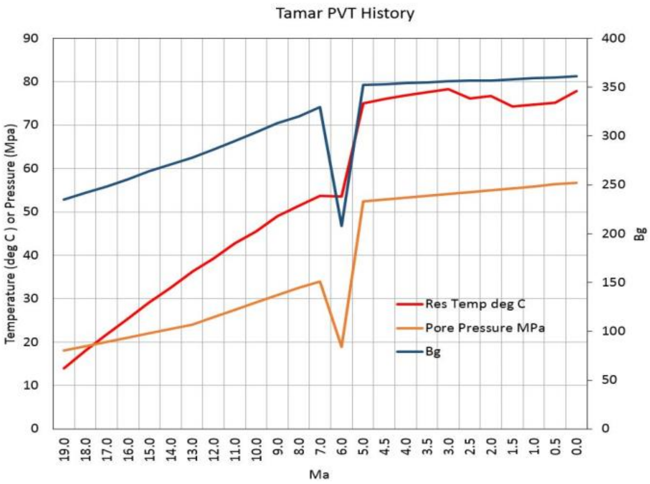


Fig 2 : Interpreted PVT History of the Tamar Field. Note the effects of the Messinian lowstand, particularly on the Gas Expansion Factor (Bg) and the flattening out of the Bg thereafter. Trap thought to have been formed between 11-19Ma with effective charge up to 7Ma.

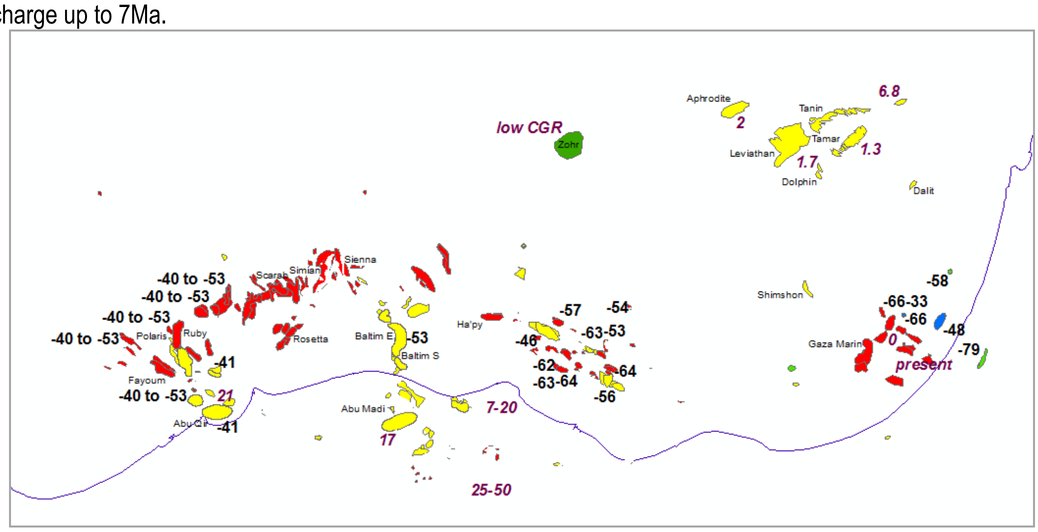


Fig 3 : Isotopic composition of methane (delC¹³) (black numbers) and reported condensate-gas ratios (CGR, bbls/MMscf, purple numbers). Values of delC¹³ below -60 0/00 are taken as indicative of a pure biogenic gas.

NOTES:

Investigating Potential Charge Mechanisms in the Levantine Basin Using 1D Basin Modelling

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[2]*MacGeology Ltd.*

The Levantine Basin holds some of the largest deepwater gas discoveries of the last decade. These accumulations are widely reported to have a biogenic source; however, reports of minor condensate yields from fields, such as Tamar, suggest there is a thermogenic contribution. Furthermore, wells located in the shallower Levantine Basin (Yam-2 and Yam-Yafo-1) have recorded both light oil shows and gas with a thermogenic isotopic composition in Middle Jurassic carbonates. This evidence of a working thermogenic kitchen raises the possibility of reservoirs deeper than the existing biogenic fairways receiving a charge.

This study uses basin modelling to investigate the maturity and timing of generation in potential source rocks and assesses the possibility of a thermogenic charge in the Levantine Basin. Data inputs were developed by integrating publicly available data with regional geological interpretations. A 1D basin model of the Tamar_4 well, calibrated using reservoir temperature measurements, is used to evaluate potential source rocks in the Early Triassic, Early Jurassic, and Oligocene epochs. The timing of the biogenic charge is also assessed. The heat flow that thermally calibrates the Tamar_4 model is then used as an input for a 1D model of a pseudowell on the flank of the Zohr discovery. Additionally, a second, lower heat flow scenario is tested at the Zohr_Flank model location.

Tamar_4 well modelling indicates potential source rocks in Triassic or Jurassic stratigraphy could have generated thermogenic gas following the mid-Miocene Syrian Arc trap formation, accounting for reported low condensate yields at Tamar. However, the majority of the charge is likely to have predated the mid-Miocene trap forming event. Deeper traps that formed earlier (e.g., Mesozoic carbonate build-ups on basement highs) potentially received a greater portion of this charge.

When potential Triassic and Jurassic source rocks are modelled on the Zohr discovery flank, a wet gas charge to the Zohr reservoir after Messinian trap formation is predicted. If the Zohr field gas contains no thermogenic contribution, as suggested by the reports to date, it can be inferred these source rocks are absent in the Zohr catchment. This could imply that Triassic/Jurassic source rock presence is restricted to the basin center. As a result, deeper plays could only be prospective where they are in proximity to the deepest parts of the Levantine rift (Fig. 1). The high level of thermal maturity within the basin center implies any discoveries within a deeper fairway are likely to be gas-rich. The Oligocene is predicted to be immature at both modelled locations.

Results of this study indicate that biogenic charge to the Tamar reservoir predates the Messinian lowstand. In the absence of significant thermogenic contribution after this event, any escaped gas, spilled as the result of gas expansion during the Messinian drawdown, would not have been replaced. Consequently, underfilled structures and corresponding fill level could pose a significant risk to smaller prospects with a similar burial history to Tamar.

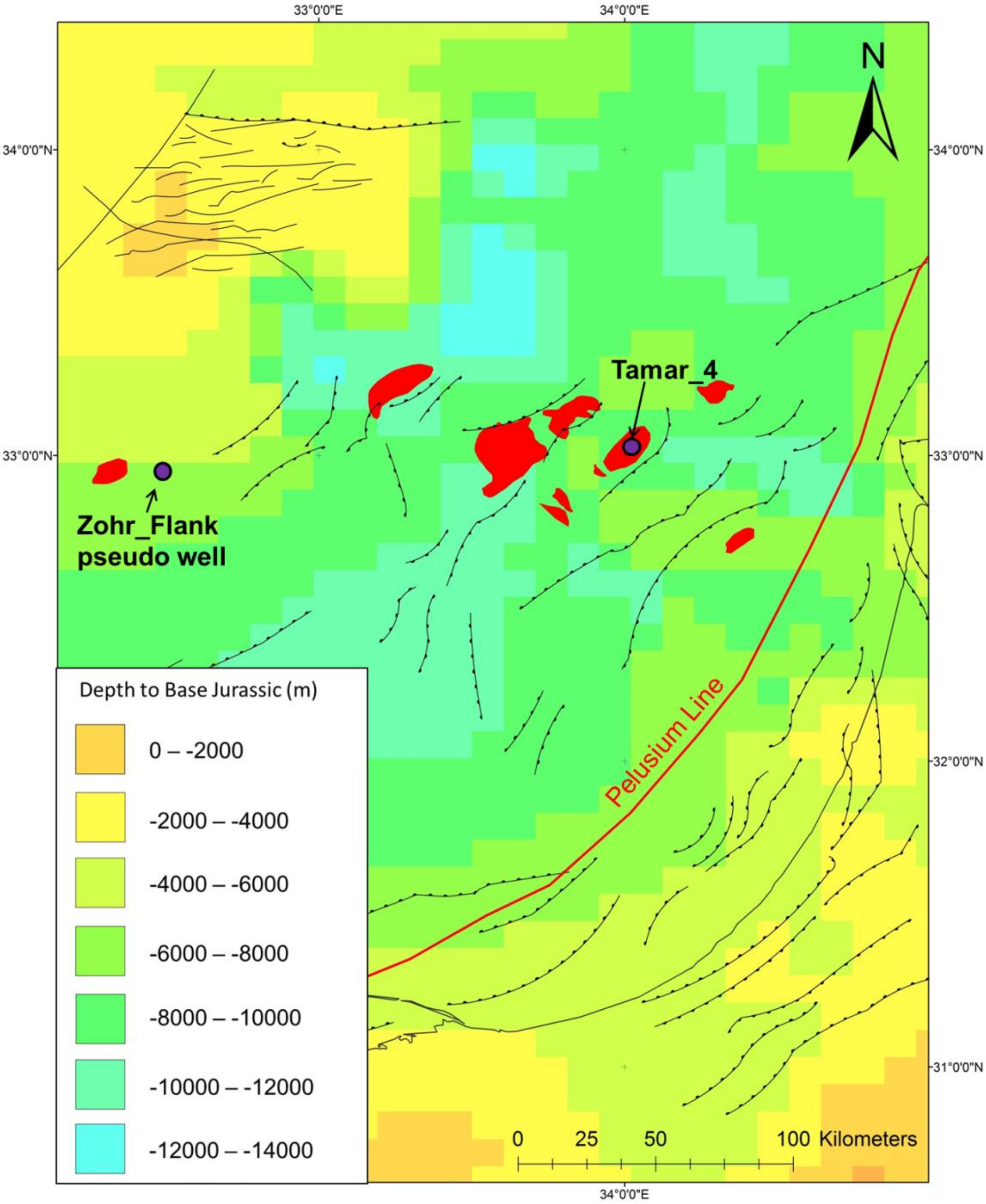

Figure 1: This map shows the depth to base Jurassic with tectonic elements and sites of 1D basin models represented by purple circles. Note the variation in burial depths; the Jurassic stratigraphy at the basin center (Tamar_4) is approximately 1.5 km deeper than that at Zohr_Flank located on the basin margin.

NOTES:

Petroleum Systems of Lebanon: recent advances and future potential

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[5]*CNRS, Beirut, Lebanon,*

The Eastern Mediterranean Levant Basin is emerging as a major petroleum province due to the discovery of more than 70 TCF of proven natural gas reserves between 2006 and 2015; fields include Tamar, Leviathan, Aphrodite and Zohr. Lebanon, part of the greater Levant region, is located on the active NW margin of the Arabian plate, the margin being largely defined by the left-lateral Levant Fracture System. To the east is the petroliferous Palmyride fold-and-thrust belt and to the west the stable foreland of the Levant Basin. Onshore, in Syria, recoverable reserves are estimated at about 2.5 billion (B) brl of oil and about 8.5 TCF of gas, with fields located in the Palmyrides, the Euphrates graben, and the Sinjar high. Therefore, Lebanon and the adjacent offshore are considered to have significant exploration potential.

In the last decade, major breakthroughs in the understanding of the Lebanese subsurface and its petroleum potential have been made. This has been possible due to availability of high quality 2D and 3D seismic reflection dataset covering the entire Lebanese exclusive economic zone, and the first, though limited 2D seismic data onshore Lebanon. These data provided a wealth of information pertinent to the exploration of the northern Levant Basin, attracting major international oil companies as well as international academic interest. Exploration agreements have been signed with the Lebanese government in February 2018, with a much-anticipated date for the first well offshore in 2019.

This contribution presents a comprehensive review of the petroleum systems of Lebanon, both offshore and onshore, based on the results of recent academic and industrial research projects, and exploration work supported by the Lebanese Petroleum Administration. The outcome of these studies resulted in: (i) an improved model of the crustal structure of the Levant Basin confirmed by deep seismic and gravity modelling; (ii) a new stratigraphic model for the Levant Basin based on seismic data, extensive fieldwork, and forward modelling; (iii) a detailed structural framework for the Levant Basin and margin based on new 3D seismic data interpretation and analogue modelling; and (iv) a thorough geochemical assessment of source rock potential supported by extensive sampling onshore and regional basin modelling, providing an updated evaluation of the hydrocarbon potential of Lebanon.

This integrated approach, involving geodynamical, stratigraphic, structural, and geochemical investigations, led to better apprehend/constrain the petroleum systems in Lebanon. For this purpose, we divide the Lebanese onshore and offshore into four domains as follow:

- *The deep Levant Basin* is characterised by siliciclastic reservoirs and is mainly dominated by Oligo-Miocene biogenic source rocks, with a possible contribution from deeper thermogenic sources. Potential structural traps include early Miocene tilted fault blocks and late Miocene four-way dip closures,
- *The Lattakia Ridge* is characterised by mainly Oligo-Miocene siliciclastic reservoirs and has probably a mixed biogenic-thermogenic source rock potential. Potential traps are Late Cretaceous four-way dip closures.
- *The Levant Margin*, subdivided into a southern, central and northern margin, is characterised by Mesozoic carbonate reservoirs together with Early Cretaceous and Oligo-Miocene siliciclastics, with predominantly thermogenic source rocks along the margin and the possibility of lateral migration from the deep offshore. Traps are mostly stratigraphic.
- *The Lebanese onshore* is characterised by Triassic dolomite reservoirs, Jurassic and Cretaceous carbonate reservoirs with thermogenic source rocks in the Lower Triassic, Kimmeridgian and Campanian. Potential traps are mostly four-way dip closures.

Each domain is characterised by a particular structural style and stratigraphic architecture, resulting in different source-reservoir-trap configurations. This new division draws attention to specific, interesting exploration areas with distinct petroleum systems, in which both thermogenic and biogenic source rocks are active. Different plays are also believed to characterise each domain. While the petroleum system in the deep basin is well understood from regional correlation, the margin and the Lattakia Ridge are associated with a higher exploration risk. Therefore, this subdivision highlights the geological variability offshore Lebanon, and could serve as a mean to assess the probability of success of plays and prospects grouped into distinct domains.

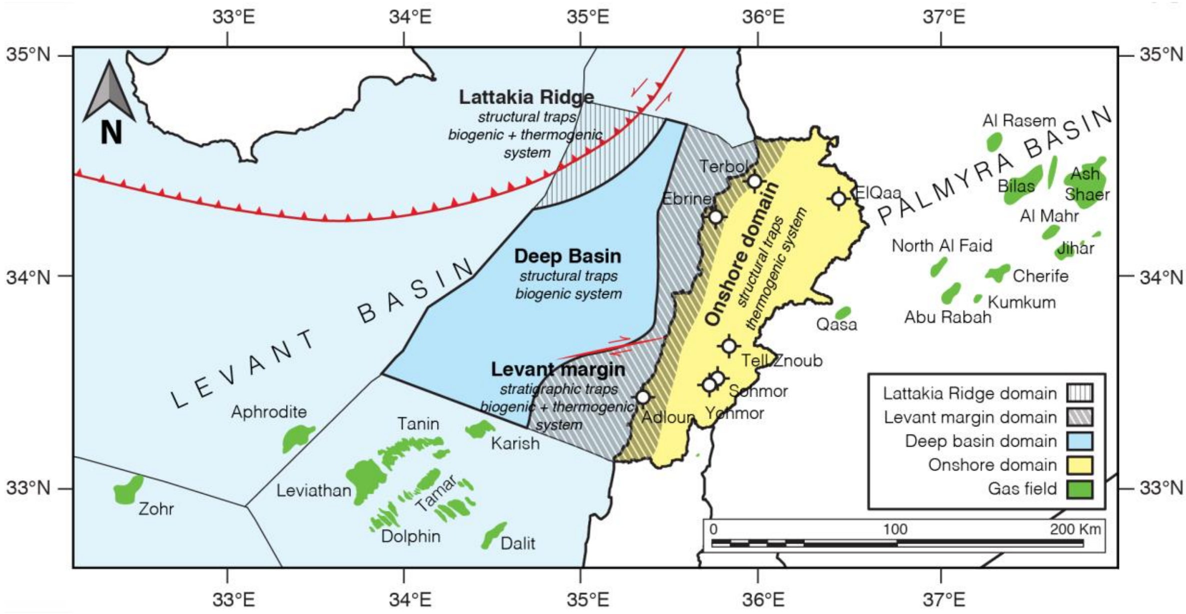

Figure showing the four distinct geological domains offshore Lebanon. These domains could help focusing exploration by drawing attention to specific plays which are unique to each area, and help explorers assessing the common risks offshore Lebanon.;

NOTES:

Pore Pressure Prediction along the Messinian Salt Structures Using Seismic Velocities of the Mersin Bay, Northeastern Mediterranean Sea

Ayberk Uyanik
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Drilling around salt structures is commonly a risky process due to the presence of unexpected overpressured-underpressured zones bearing a risk of mud-leakage, kicks or blow-outs especially when a well is proposed in a vast offshore area with a very limited well log data control. Therefore, due to the absence of reliable well log data, consideration of different methods for pre-drill pore pressure estimations is essential to assess and decide the type and weight of the drilling-mud and prevent the drilling hazards. This study introduces a method aiming to reduce the uncertainties in the wild-cat offshore areas by focusing on the Messinian salt structures in the Mersin Bay (Fig.1).

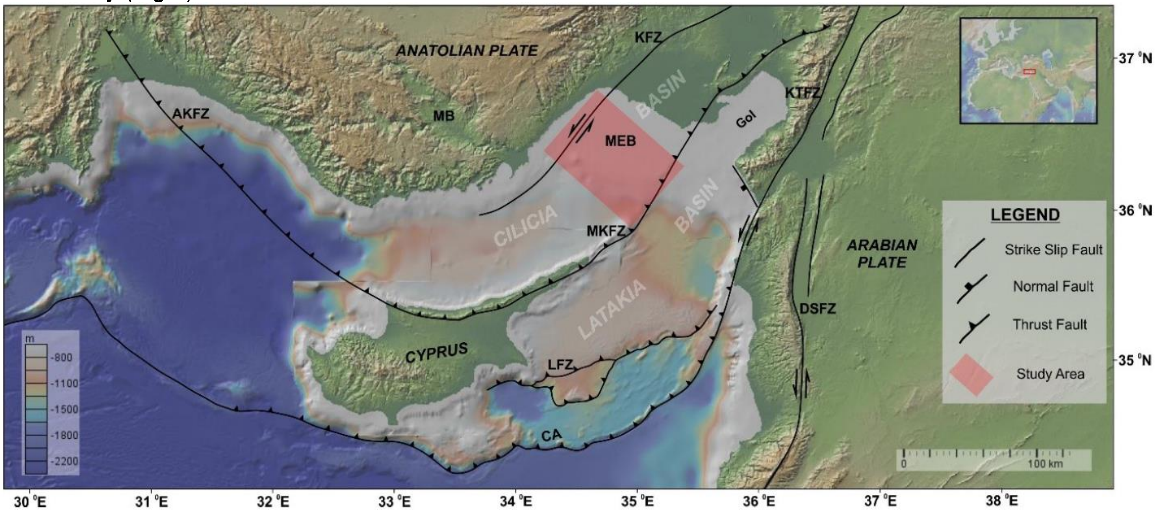

Fig 1. The map depicting the regional tectonic elements in the NE Mediterranean Sea
(KFZ: Kozan Fault Zone, MKFZ: Misis-Kyrenia Fault Zone, DSFZ: Dead Sea Fault Zone, LFZ: Larnaka Fault Zone, AKFZ: Aksu-Kyrenia Fault Zone, KTFZ: Karatas Fault Zone, CA: Cyprus Arc, MEB: Mersin Bay, GoI: Gulf of Iskenderun, MB: Mut Basin)

The Messinian salinity crisis that influenced the Mediterranean region approximately 5.96 Ma ago, resulted with the deposition of thick evaporitic sequences in the Mersin Bay as well, characterised by halite, gypsum and anhydrites. By the onset of Zanclean flooding event, 5.33 Ma, the Pliocene sediments started to deposit in a pull-apart basin, formed between two parallel NE-SW oriented sinistral strike-slip fault zones. High sedimentation rates provided by the Pliocene deltaic successions increased the sediment loading on the Messinian salt, forcing them to migrate into salt rollers bounded by listric normal faults. Withdrawing salt also contributed into reactive diapirism process and caused the occurance of a complex geology in the region. In order to provide an approach to the pressure profiles along these structures, interval velocities corresponding to shot points of 2D seismic lines have been converted to pre-drill pore pressure cubes, both in psi and ppg, using Gardner's and Bower's equations.

The advantage of the method is its' ability to demonstrate the vertical and lateral changes in the values. Generated cubes can be reflected on the seismic sections to interpret them more accurately, establishing a broad understanding for the geology of the region (Fig.2).

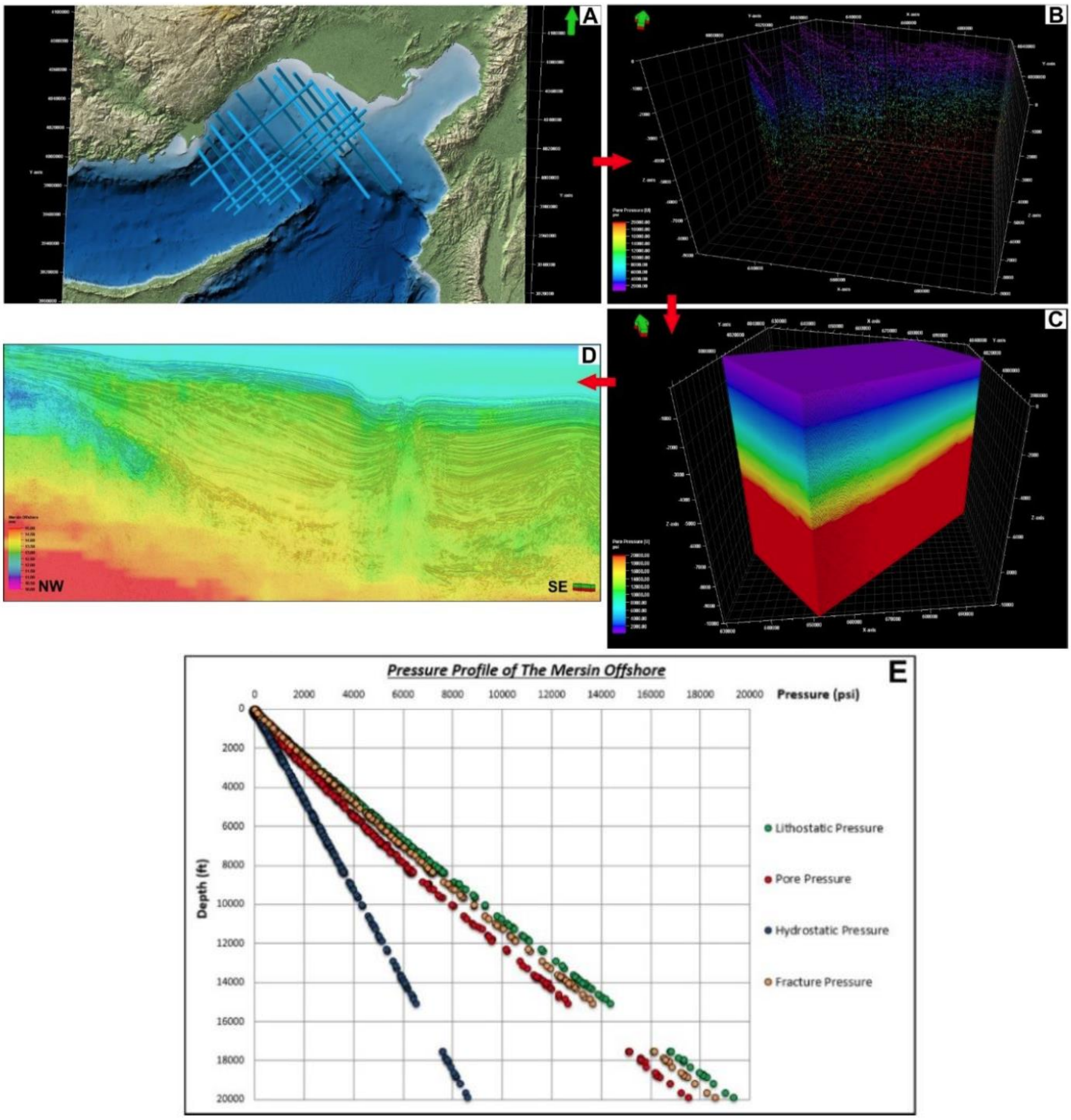

Fig 2. Images illustrating the creation of pre-drill pore pressure cubes
(A: Point data extraction, B: Upscaled point data in 3D view, C: Generated pore pressure cube in 3D view, D: Reflection of pore pressure cube on 2D seismic data, E: Graph demonstrating the pressure profile of the Mersin Bay)

The reflected pore pressure cubes indicate that the salt structures in the bay act as a regional pressure boundary between supra-salt and pre-salt sediments. An overpressured zone with 15-17 ppg, experienced by K-1 well by four kicks, is located below the salt structures while abrupt increase in the pressure values dominate the sediments sitting directly on the salt rollers. Pressure profiles can also be used to determine the migration pathways by following the salt welds where the pressure boundary does not develop due to the thinning or absence of salt. On the other hand, the Pliocene deltaic succession, represented by clinoforms and delta plain channels, includes pressure anomalies indicating potential fluid bearing reservoirs. As a conclusion, the method can be considered as an effective way to reduce the operational risks in the early phases of the exploration activities. Moreover, it can be used for the utilisation of the undiscovered resources in the wild-cat salt including basins of the Mediterranean Sea.

NOTES:

Egypt's West Mediterranean Sea – An Exploration Opportunity

Matthew Pyett, Simon Baer *PGS*
Ayman El Morshedy *EGAS (Egyptian Natural Gas Holding Company)*

Despite lying in the neighbourhood of one of the most prolific petroleum provinces of Africa, Egypt's West Mediterranean Sea has seen exploration efforts limited by a lack of data and clarity of license block delineation. Recently acquired 12km long offset GeoStreamer® seismic data, together with anticipated licence round activities has suddenly thrust this area to the forefront of oil companies exploration plans in 2018.

Egypt's West Mediterranean Sea is bounded to the south by the Egyptian mainland that encompasses the mature Western Desert basins and to the east by the prolific Nile Delta cone where multiple discoveries have been made to date.

This frontier study area covers approximately 80,000 sqkm, available data includes re-processed legacy 2D seismic data alongside newly acquired GeoStreamer 2D seismic and gravity and magnetic data provide new insights into the hydrocarbon potential of Egypt's West Mediterranean Sea. Existing 3D seismic surveys are currently undergoing reprocessing. The available dataset includes approximately 17,500 line km of 2D and 6000 sqkm of 3D (Figure 1).

The area can be divided into the following geological domains, from south to north, a shelf zone including two distinct S-N trending canyons and a narrow Transform Margin. North of the Transform Margin, the area can be divided into three parts including, from west to east, the Mediterranean Ridge, the Herodotus Basin and the Nile Delta extension (Figure 2).

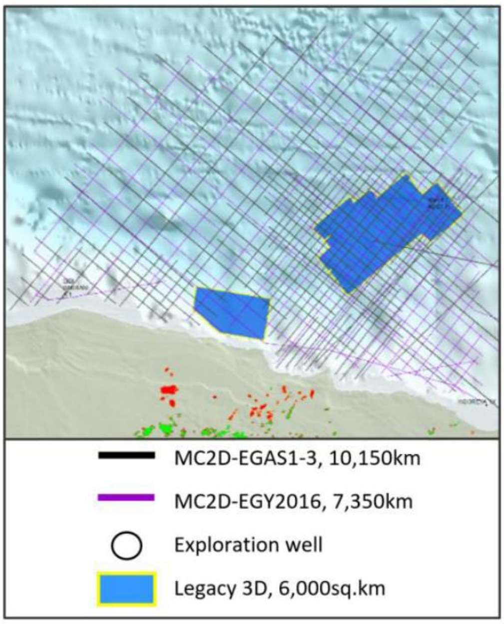

Figure 1: PGS 2D & 3D seismic Database.

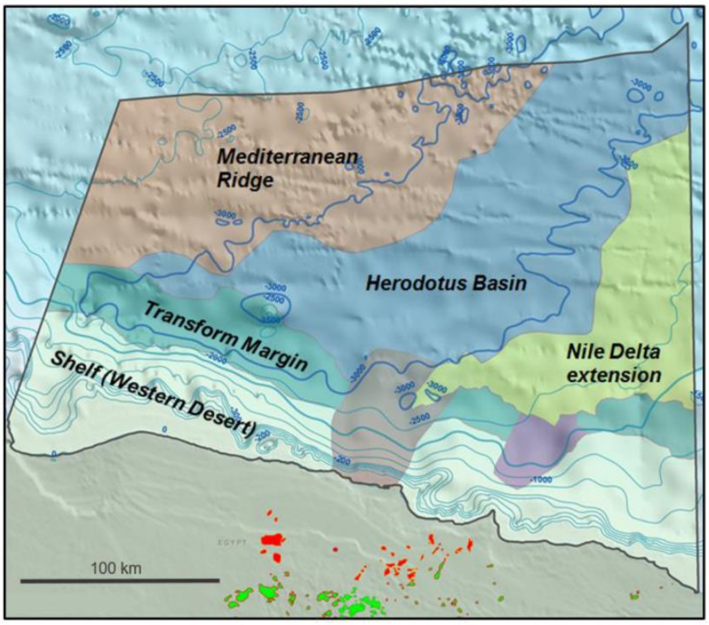

Figure 2: The offshore area has been subdivided above into six offshore geological domains based on seismic interpretation.

The gravity and magnetic data provides strong indications for the continental/oceanic crust boundary, which identifies that the entire Shelf, Transform Margin and both canyons are located on continental crust. Consequently all leads present across these three geological domains are located on continental crust. Within the basin, the gravity and magnetic study and the seismic data confidently suggest a maximum sediment thickness of approximately 15km, which allows a working petroleum system to be in place.

Based on a combination of the reprocessed and newly acquired 2D datasets, several leads are identified throughout the area through a comprehensive interpretation process. These are mapped out and supported by a basin modelling study, which indicates that several source rocks could have generated and expelled hydrocarbons (notably Oligo-Miocene biogenic gas and Early Cretaceous - Eocene source rocks). The leads can be assigned to the following play types:

- Pliocene deep marine clastic play, which is a proven play in the western part of the Nile Delta/Cone.

- Oligocene/Miocene sub Messinian Salt clastic play, which is a proven play to the east in the Nile Delta/Cone, where it is defined as a ´lowstand incised valley/submarine canyon play`.

- Cretaceous carbonate play covering the Transform Margin, consisting of either erosional or build up carbonate structures, potentially of significant areal extent (potentially > 150km²).

- Cretaceous and Jurassic carbonate platform play over the Shelf as a possible extension of the proven onshore Western Desert discovery trend.

- Cretaceous and Jurassic clastic play (Alam el Bueib Formation and Khatatba Formation respectively) on the Shelf as a possible offshore extension of the proven onshore discovery trend.

- Cretaceous traps within the Herodotus Basin developing due to the Late Cretaceous-Eocene inversion.

- Syn-rift and post-rift roll over structures generated due to a shale detachment surface and syn-rift Jurassic highs within the Matruh Canyon and Canyon East.

By considering a promising carbonate play together with the outcome of the gravity and magnetic data, the basin modelling results and the above mentioned plays of Jurassic to Pliocene age, Egypt's West Mediterranean Sea contains all aspects relevant for a potentially prospective working petroleum systems. Therefore Offshore West Egypt is rapidly attracting attention as a potential new petroleum province in the Eastern Mediterranean.

NOTES:

Seismic indicators of focused fluid flow and cross-evaporitic seepage in the Eastern Mediterranean

C. Bertoni[1], C. Kirkham[1], J. Cartwright[1], N. Hodgson[2], K. Rodriguez[2]
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We present a synthesis of the evidence of focused fluid flow in the Eastern Mediterranean, providing an updated record that includes recent and past occurrences through the last ca. 6 My of evolution of the basin. Our interpretation shows a high number (141) of focused fluid flow features, which span the stratigraphic interval from late Miocene to Recent. Of these features, 82 are at the seabed, and 59 are buried. The spectrum of buried and seabed features covers pockmarks, pipes, mud volcanoes, clastic intrusions and collapse structures.

Clustering of the fluid flow features is observed at different times in specific areas, including the Nile Cone, and the Levant, Herodotus, Cyprus and Latakia basins. With the buried record, we are able to highlight the evolution of the leakage points through time. Focused fluid flow venting has been occurring since the start of basinwide deposition of Messinian evaporites. We focus in particular on seismic indicators of leakage through evaporites, and of sub-evaporitic source for fluids and remobilized sediments. We also discuss the role of the evaporites as a seal to ascending fluids, and in which circumstances they can be breached.

Fluids (and associated remobilised sediments) are sourced from different intervals, from the sub- and supra-evaporitic section, and possibly within the evaporites. Only a minor proportion of the fluid flow features are certainly rooted below the Messinian evaporites, and most of them are located in the Nile-Levant-Eratosthenes areas. The few examples of pathways that are able to cross thick, undeformed and well preserved evaporites are typically correlated to overpressure release and hydrofracturing.

This confirms that the evaporites do act regionally as a very good seal as expected, while fluids are able to cross the evaporites only in their most extreme expression, i.e. in near-lithostathic overpressure conditions. Our observations made in the Eastern Mediterranean support the idea that in the presence of relatively undisturbed evaporites, cross-evaporite vertical fluid pathways are only observed at the high end of the flux-pressure range, and involve sediment remobilisation. Maps combining these different elements can be used for detecting areas potentially more prone to high overpressures and breaching.

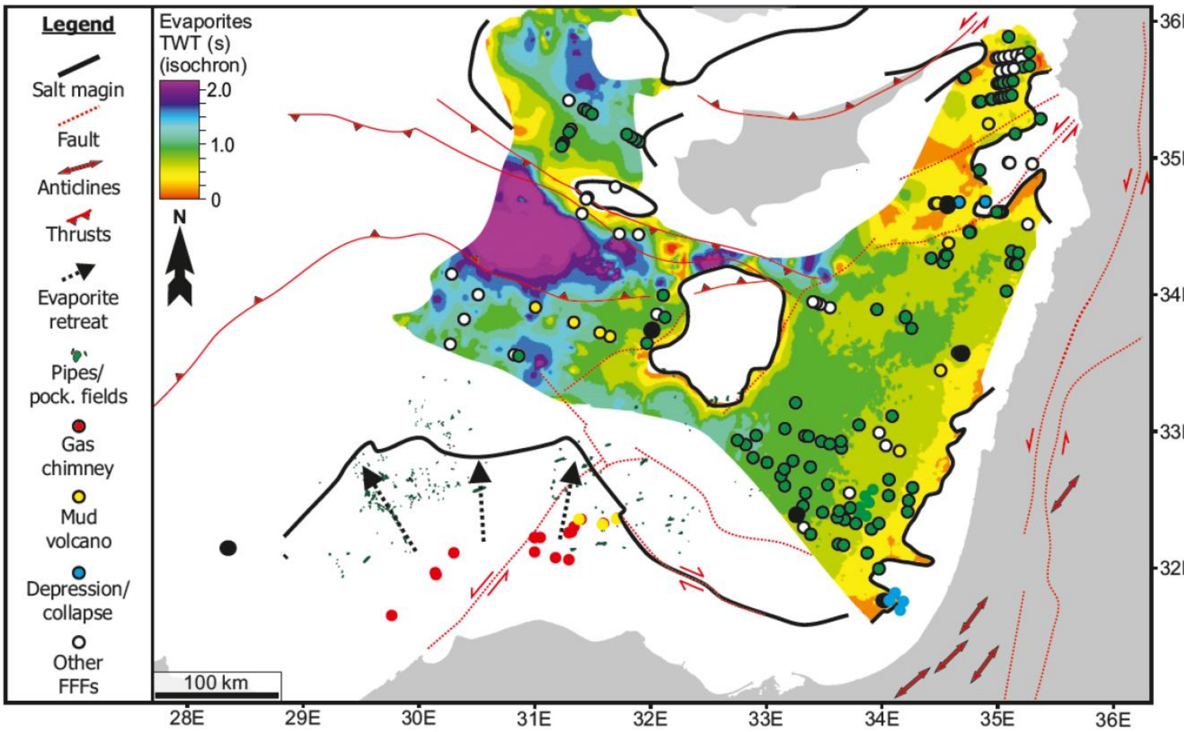

Figure: TWT thickness (isochron) map of the Messinian evaporites (Bertoni et al., 2017). The black dots indicate the fluid flow features with cross-evaporitic conduit or sub-evaporitic source. The large black arrows indicate retreat of the evaporite pinch-out, due to dissolution and deformation (Allen et al., 2016; Bertoni and Cartwright, 2006; Loncke et al., 2006). The outline of the present-day pinch-out of the Messinian evaporites in the Nile Cone area is from Loncke et al. (2004). main tectonic elements from previous studies (Robertson, 1998; Tibor and Ben-Avraham, 1992; Vidal et al., 2000). Evidence of fluid flow features is compiled from Bertoni et al. (2017), Loncke et al. (2004), Netzeband et al. (2006), Bertoni & Cartwright (2005), Dupre et al. (2007), Frey et al. (2007), Hubscher et al. (2009), Bowman (2011), Lazar et al. (2012), Bertoni et al. (2013), Mascle et al. (2014), Reiche et al. (2014), Eruteya et al. (2015).

NOTES:

Episodic gas venting from subsalt gas accumulations in the Levant Basin: implications for charge and overpressure in pre-salt plays

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We present evidence for episodic gas venting from a large anticlinal trap in the Levant Basin. Using a high resolution 3D seismic survey from offshore Lebanon, we identified a series of 21 fluid expulsion craters (pockmarks), with typical dimensions of 500m diameter, and 30m incision depth within the Late Pliocene to Recent stratigraphy. These pockmarks define a diachronous trail, oriented WNW-ESE approximately orthogonal to the basin margin, with a systematic younging to the ESE. The youngest pockmark is at the seabed and at the upper terminus of a c.2.4km tall fluid escape pipe, that emanates from a gas-charged reservoir of early Miocene age. This pipe roots at the crestal position of a major anticline developed in the pre-salt stratigraphy, crosses a clastic topseal, followed by a c.1km thick salt sheet of Messinian age consisting mainly of halite. It then transects the entire post-salt overburden to emerge at the seafloor. 3D attribute analysis (amplitude and coherency) within the salt and overburden allow us to interpret a strong and continuous reflection that links the oldest pockmark to the root zone for the youngest pockmark.

We interpret this curvilinear reflection feature as a deformed equivalent of the modern fluid expulsion pipe. Originally vertical and cylindrical, we argue that it has been deformed by flow of the salt sheet in the past c.2Ma. The deformed geometry of the pipe thus represents a strain marker for long term salt flow. We suggest that following this initial natural blow out, which involved pore fluids as well as reservoired hydrocarbons, the reservoir re-pressured, possibly due to re-charge or due to continued compressional amplification of the anticline, or both. Twenty successive blow-outs occurred in the following 2Ma, giving an average interval of 100ka between venting episodes. Fluid pressures must have been close to or at lithostatic in order for hydraulic fracturing to punch a permeable pathway through the clastic and evaporitic overburden. This episodic, fracture induced seal failure points to the development of localised ultra-high pressure cells where aquifers impose a significant pressure on their overlying hydrocarbon columns. Seal failure in this pre-salt structure is therefore dominantly driven by aquifer pressure changes and not critical buoyancy pressure.

NOTES:

A newly discovered giant anticline of early Mesozoic age in the Levant basin

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Dakar anticline, a deeply buried giant fold of Triassic-early Jurassic age has been revealed recently from depth imaging of a 3D seismic data-set acquired in the Levant basin offshore Israel. The excellent quality deep seismic depth imaging provides the first clear evidence for an early Mesozoic folding phase in this part of the basin, where previous structural interpretations have suggested a pattern of early Mesozoic horsts and grabens formed in an extensional tectonic regime, related to rifting and opening of the Neo-Tethys.

Structurally, the anticline, which only part of it is covered by the seismic data-set, is associated with a distinct magnetic anomaly, indicating a basement involved structure. Within the mapped area the fold is characterized by its large reconstructed size, semi-circular shape, lack of significant fault control and lack of distinct trend patterns. Accordingly the structural style is classified as a basement involved dome, meaning dominant vertical movements in Triassic-early Jurassic time, in this part of the basin.

The crest of the dome is buried under 6000 meters of Senonian and younger sediments. Over 2000 additional meters of interpreted Cretaceous to mid or even early Jurassic sediments onlap on its flanks. Stratigraphically, the upper sequence in the fold exhibits characteristics of a mobile sediment, such as soft shale or a mixture of shale and salt. It is chaotic to transparent, distorted and typically thickens considerably toward the structural crest, forming a crestal diapir penetration into overlaying Senonian to Oligocene sediments.

The newly discovered fold provides a novel insight into the early Mesozoic tectonic evolution of the southern Levant basin. The large fold topped by excellent sealing sediments highlights new potential objectives for future hydrocarbon exploration in the basin.

NOTES:

Wednesday 30th May 2018
Session Three: Fields and Analogues

KEYNOTE: The Dynamic Tamar Reservoir - Insights from Five Years of Production

Jesse Ortega[1], Russell Hebert[1] and Yedidia Gellman[2]
[1]*Noble Energy Inc., Houston, Texas, U.S.A.*
[2]*Delek Drilling, Herzilya, Israel*

The Tamar Field was discovered offshore Israel in early 2009, and proved the presence of a new gas play in the Miocene-aged sediments of the deep Levant Basin. Subsequent discoveries in this "Tamar Sands" Play (e.g. Leviathan, Aphrodite, Karish, and Tanin) total over 40 Tcf of recoverable resources.

Tamar is an elongated anticline, trending NE-SW. The field consists of three vertically stacked gas bearing reservoir intervals (A, B, and C Sands), which are separated by shale-dominated zones (AB and BC Shales). Seismic and well data confirm the lateral continuity of the major sand and shale units. The high-quality reservoirs were deposited in a relatively unconfined environment as compensationally-stacked basin floor fans, and are juxtaposed across post-depositional NW-SE striking normal faults. The reservoir intervals have a very high net-to-gross (75% to 95%), in predominantly fine-grained sands. Average total porosity ranges from 21% to 23%, and gas core permeability values average 600 to 1200 mD. Thin shale beds are also present within the reservoir intervals, and have the potential to baffle fluid flow. Many of these thinner shale beds are debritic in nature, while others are laminated components of heterolithic packages. Prior to production, all reservoir penetrations encountered a single Gas-Water-Contact (GWC), strongly suggesting hydraulic-connectivity over geologic timescales.

To date, six high-rate (~250 MMscf/d) production wells have been drilled and completed in the field. The wells are equipped with downhole pressure-temperature (DHPT) gauges located approximately 250 meters above the completed sand face, which provide high frequency production data for reservoir monitoring and performance analysis.

The subsea wells are tied back to the Tamar Platform via a subsea manifold and two 150km gathering lines. Since Tamar is presently the sole supplier of natural gas to the Israeli market (excluding minor LNG imports and production from the nearly-depleted Mari B Field), the production rates are directly driven by market demand. This dependency creates a cyclic pattern of production rates on a daily, weekly, and seasonal basis. These cycles challenge both operations and conventional methods of reservoir performance analysis.

Well pressure data are collected continuously from the DHPT gauges, and provide a history of pressure/temperature drawdowns and buildups throughout the life of each well. Pressure Transient Analysis (PTA) of the buildup data is used to monitor completion efficiency as well as to constrain and forecast reservoir performance. PTA-derived permeability, well interference signature, and reservoir pressure decline are all used to study a reservoir's dynamic properties.

This study integrates these dynamic methods with the geological database, and particularly with data from the recent Tamar-8 well. Tamar-8 was drilled in late 2016, close to 4 years after first gas. Tamar-8 was drilled to a TD below the lowest reservoir and then plugged back, sidetracked, and completed as a high rate producer. The pilot hole allowed full evaluation of partially depleted sands and a water-encroached swept zone. Wireline logs, pressure tests, and fluid sampling from this well provided valuable insights into reservoir dynamics, and enabled an improved calibration of both geologic and reservoir engineering models.

The PTA and Material Balance results indicate that the wells are draining large extents of the reservoir, and that all wells are in communication either through the gas and/or through the aquifer. These conclusions are supported by pressure data from Tamar-8. Furthermore, the datasets confirm cross-fault communication, some degree of stratigraphic baffling, and a combination of both volumetric depletion and aquifer support.

The integration of "dynamic data" (continuous production parameters) with "static data" (seismic, well logs, cores) indicates that the reservoir is indeed continuous and exhibits a high degree of hydraulic connectivity. Additionally, small scale features that impact flow on production timescales are now better understood. These types of insights may inform development decisions such as the timing and location of future wells. At Tamar, geoscientists and engineers continuously reevaluate both static and dynamic reservoir models. This collaboration is enhancing the original concepts for reservoir connectivity and performance, and is expected to result in an optimized development plan for the management and production of the field.

NOTES:

Application of fault seal analysis for field development planning of Karish and Tanin gas fields, offshore Israel

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The Karish and Tanin fields are predominantly biogenic gas accumulations with thermogenically sourced liquids, multiple stacked reservoirs located within the Levant Basin offshore Israel. Both fields are part of the regionally prolific Early-Miocene Tamar Sands play, with Karish and Tanin together containing some 2.4 tcf of gas and more than 33 mmbbl of condensate (2P contingent resources). Seismic interpretation has shown the presence of numerous multiscale faults, resulting in complex structures as shown in Figures 1 and 2. The degree of structural complexity has a direct effect on reservoir compartmentalisation potential, and gas recovery factors. Classifying faults based on their fluid-flow behavior and understanding their influence prior to production is of critical importance for field development planning and production performance predictions.

Structurally consistent seismic attributes (DHIs) calculated over multiple consecutive structures indicate a common gas-water contact, suggesting cross-fault pressure communication and most likely reservoir fluid connectivity on a geological time scale. Nevertheless, these faults could act as dynamic baffles to flow on a production time scale, by merely inducing zones of significant permeability contrast.

Complete fault seal studies were conducted by applying industry-standard quantitative methodologies for analysing and predicting the sealing behavior of faults in clastic reservoirs. Initially, seismic-scale interpretations integrated with structural analysis tools were used to construct geologically and geometrically justifiable 3D structural models. Fault clay content was then predicted using algorithms such as the Shale Gouge Ratio (SGR). The calculated fault clay content was calibrated at reservoir-to-reservoir juxtapositions against global equations to calculate the sealing potential of the faults, supporting the observed DHIs. Furthermore, fault permeabilities and thicknesses were predicted empirically from petrophysical and fault geometry attributes of the initial geological models. Eventually, the predicted fluid-flow properties were used to construct robust and geologically sound fault transmissibility models. Subsequent reservoir simulations showed the impact of faults on fluid flow and recoverable volumes, based on a number of production well configuration scenarios.

The future integration of production data, permanent downhole pressure gauge measurements, together with 4D (time lapse) seismic monitoring of the reservoir fluid distribution, will further contribute to refining and constraining the reservoir model and associated attributes such as fault seal estimates and transmissibilities.

In conclusion, fault seal analysis provides a sound method for examining the impact of fault attributes on de-risking exploration prospects and development planning in terms of fluid distribution compartmentalisation, well placement and consequently limiting the uncertainty on hydrocarbon recovery.

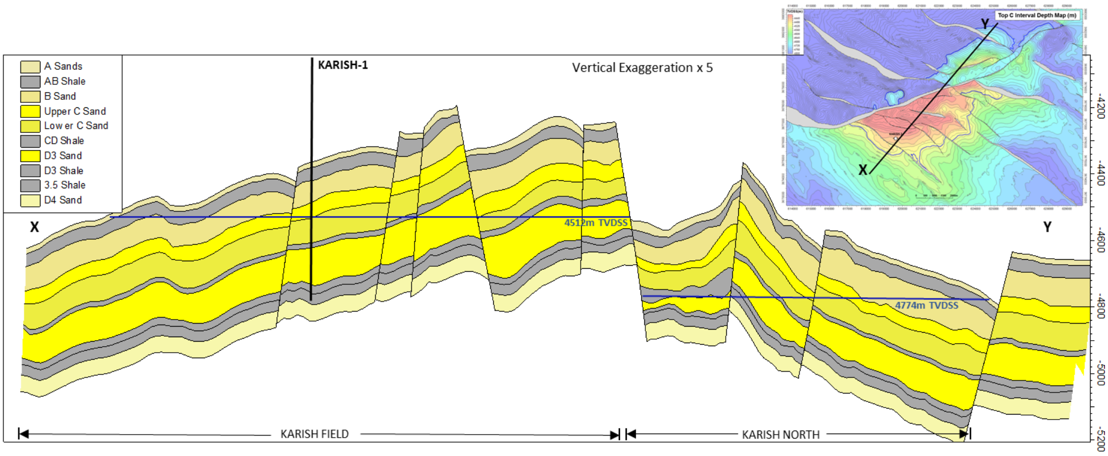

Figure 1:Cross-section through Karish and Karish North highlighting the two continuous intra-reservoir gas-water contacts.

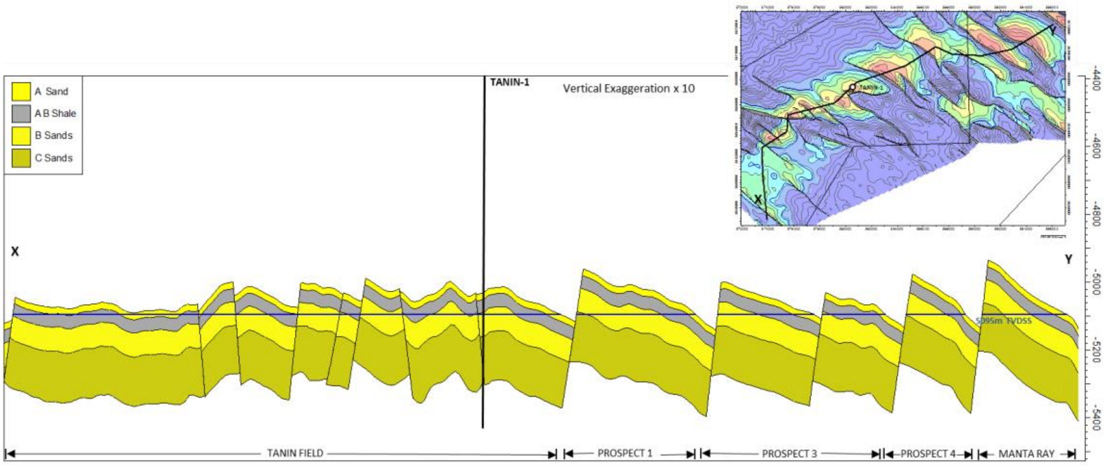

Figure 2: Cross-section through Tanin and Block-12 highlighting the common gas-water contact throughout the whole structure.

NOTES:

The South Disouq Gas Discovery, Onshore Nile Delta, Egypt

Stephen Jackson
SDX Energy Inc.

The South Disouq gas discovery confirms an extension to the prolific Nile Delta Abu Madi trend.

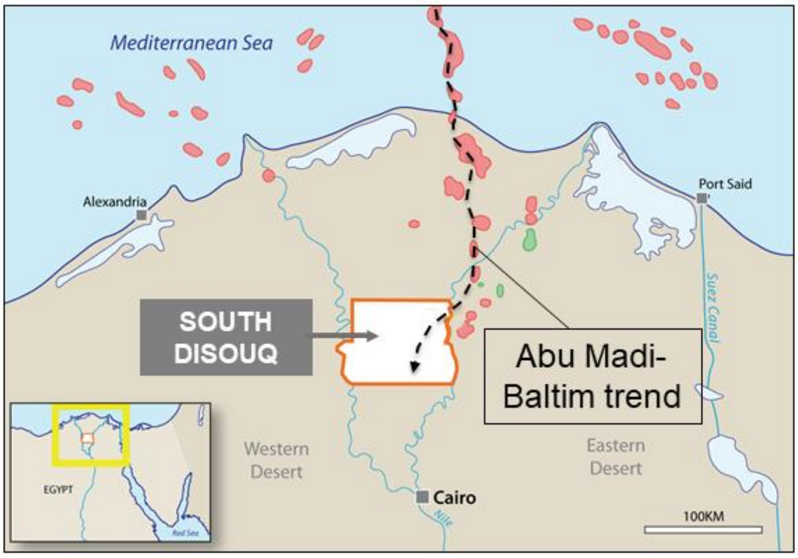

Figure 1. Location Map

Awarded to SDX Energy in 2014, the South Disouq block was underexplored, being sparsely covered by 2D seismic data of various vintages and penetrated by just one (dry) hydrocarbon exploration well. With our partner, IPR Energy Group, a 300 square kilometre 3D seismic survey was acquired and processed during 2016. Many prospective features were identified, including the South Disouq four-way dip closure which was quickly high-graded to a drill ready prospect, tested by the SD-1X well.

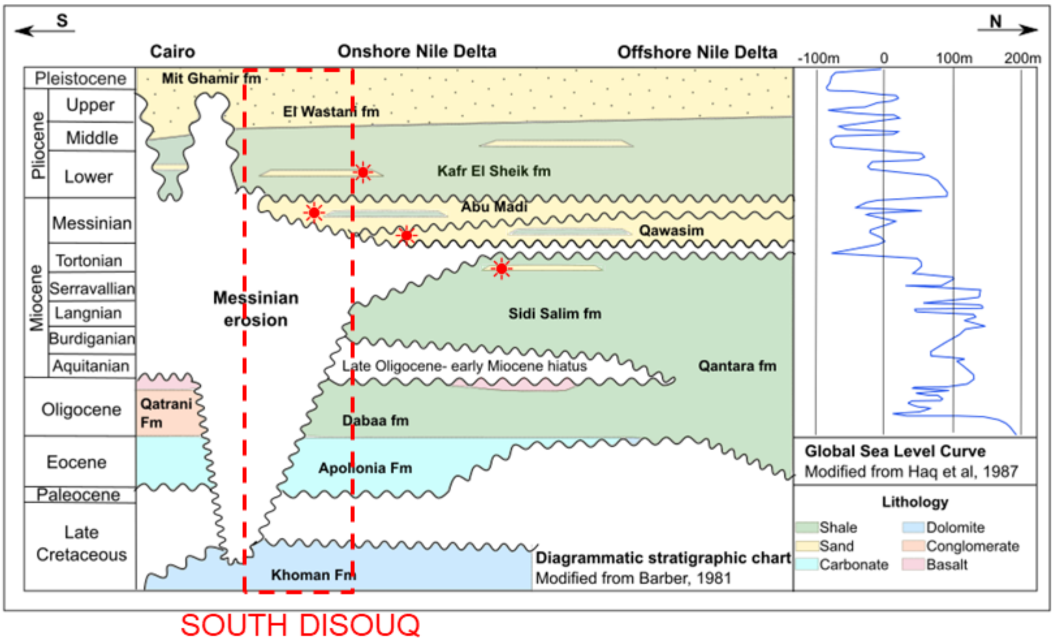

Figure 2. Stratigraphic Summary

SD-1X reached TD in May 2017, confirming 82' of gas pay in a shallow marine to fluvial sandstone. Palynological analysis of drill cuttings confirms the gas bearing section to be of Late Miocene Abu Madi age, an 811 ft section comprising abundant clean sand which becomes more shale prone near the top. The well was completed and has been tested at 26 MMSCF/d, a rate which was constrained by surface equipment.

SDX has submitted a development plan, applied for a development licence and has started permitting and tendering to enable first gas production in 2018.

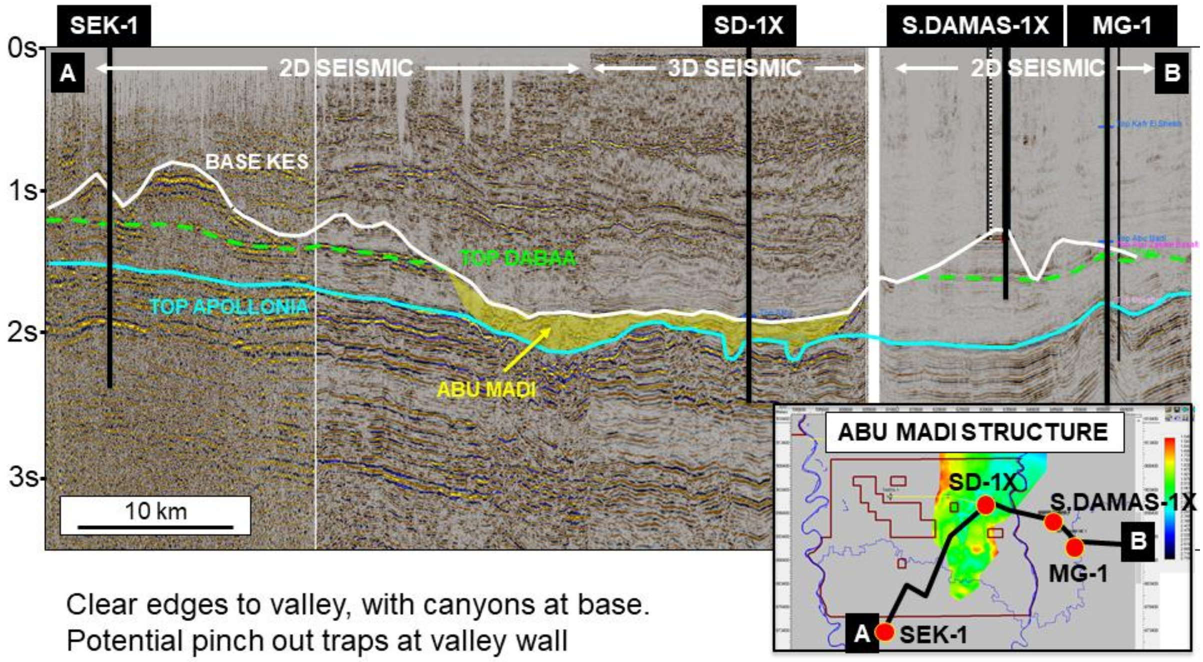

Figure 3. Regional Seismic Section

Success at SD-1X has effectively de-risked the Abu Madi play in the concession, and by integrating the discovery well and seismic data, significant further potential has been identified in the concession. Two development wells and two exploration wells are planned for 2018.

NOTES:

Depositional facies and local distribution of pre-Messinian reservoirs in Southern Crete: A key analogue for the Eastern Mediterranean Basin

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The Langhian-earliest Messinian evolution of the Eastern Mediterranean region is marked by intense tectonic movements that occurred in response to changes in the convergent vectors between Africa and Eurasia, with subsequent rollback of a subduction slab in the Aegean region. As a result, outcrops in Greece, Crete, Turkey and Cyprus record a first phase of crustal fragmentation in the Mid Miocene, which led to an abrupt Late Miocene syn-tectonic phase with widespread deposition of marine to deep-marine strata. On Crete, slab rollback occurring after the Langhian led to the formation of a series of extensional basins with general N20 and N70 orientations, now exhumed to expose syn-rift strata.

This talk will use geological maps, regional transects, outcrop lithological columns and photos from SE Crete to present particular aspects of units resulting from footwall degradation during the Late Miocene. As a crustal block positioned in the Central Aegean Sea during the Early Cenozoic, the study area recorded hyperextension in the Oligocene-Early Miocene and top-to-south movement above a crustal detachment. This movement originated a highly faulted, brittle succession (Tripolitza unit) that was displaced ~200 km above a low-angle detachment fault, the Cretan detachment. The Tripolitza unit was later eroded and offset by a series of N20^{o}E and N70^{o}E faults that bound modern transtensional basins over the Cretan detachment.

Late Miocene-Early Pliocene subsidence recorded the deposition of fluvial systems, alluvial fan deltas, submarine mass-wasting deposits, turbidites and fine-grained hemipelagites in this stratigraphic order, precluding an abrupt sea-level drop in the Messinian. Reservoir units sourced from both nearby and distal sediment sources. This work shows that proximal depocentres accumulated continental and shallow-marine units, whereas the most distal sub-basins in SE Crete were filled by deep-marine turbidites and mass-transport deposits. Detailed geological maps and transects reveal that depositional facies in SE Crete were controlled by: a) their relative proximity to active faults, b) relative position (depth and altitude above sea level) of uplifted footwall blocks, and c) nature of basement units that were eroded from adjacent footwall blocks. Paleorelief was a key factor controlling deposition, and depended on the quantity of sediment delivered to fault-bounded continental slopes and variations in base-level imposed by active faults.

This talk will conclude that similar depositional architectures to SE Crete developed during the Late Miocene in tectonically active basins of the Eastern Mediterranean. Many of these basins are the focus of hydrocarbon exploration at present, and may contain stratigraphic units of equivalent reservoir potential. Similar depositional units to SE Crete are also expected in syn-rift continental-slope basins of continental margins.

NOTES:

Presence of bottom currents and their effects on the Late Oligocene to Early Miocene deposits around the Cyprus Arc and the Eastern Mediterranean.

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Oligo-Miocene sedimentary units are found in sub-basins both on- and off-shore of Cyprus, where these units are coeval with the Tamar Sands gas reservoirs of the Levantine Basin which have high porosities and lateral continuities. Onshore Cyprus, Oligo-Miocene units are present as the Lefkara and Pakhna formations, which are described in literature as one of the best examples of ancient bottom current deposits. Offshore Cyprus, separated by the Cyprus Arc, bottom current deposits can be found in the West Eratosthenes sub-basin, located on the western flank of the Eratosthenes Seamount. To define the presence of the bottom currents, a three-stage approach for contourite identification was carried out on the Lefkara and Pakhna formations on two outcrops onshore, Agios Konstantinos and Petra Tou Romiou sections, for the Late Oligocene to Early Miocene sequences. Observations from macrofacies and microfacies analyses show coexistence of three sedimentary facies in a distal environment, with their processes and deposits: turbidites and mass-transport deposits (MTDs) from density currents, pelagites from pelagic settling, and contourites from bottom currents. Subjected to constant background pelagic settling, the fluctuation of bottom current intensity and sediment supply from turbidity current determine the facies-type deposits in the basin. The evolution from Late Oligocene to Early Miocene involved the steepening of the physiography of basin margins due to continuous uplift, caused by the ongoing subduction of the Cyprus Arc, which increased sedimentation rate from slope failure and further enhanced local bottom current intensity. Similar interpretations can be correlated to the offshore West Eratosthenes sub-basin through seismic analysis, with contourite drifts and deposits identified from morphologies such as erosional and depositional features. However, there could be a difference of effects for either side of the Cyprus Arc due to the subduction process. The relative stronger uplifting would generate stronger bottom current intensity for onshore Cyprus, compared to the West-Eratosthenes sub-basin, while the diagenetic alterations from tectonism that obliterated porosities for the outcrops onshore might not affect the reservoir presence offshore Cyprus. Furthermore, other positive petrophysical attributes associated to the outcrops onshore could be correlated offshore to have positive implications for reservoir quality. Hence, a more comprehensive understanding of the tectonics of the Cyprus Arc is key to unravel the simultaneous evolution of both sub-basins and their sedimentary processes, as well as the influence of bottom currents and its implications to reservoir characteristics in the Eastern Mediterranean.

NOTES:

Discovery of a fluvio-lacustrine system provides new constraints on the Messinian salinity-crisis: Insights from the Levant basin

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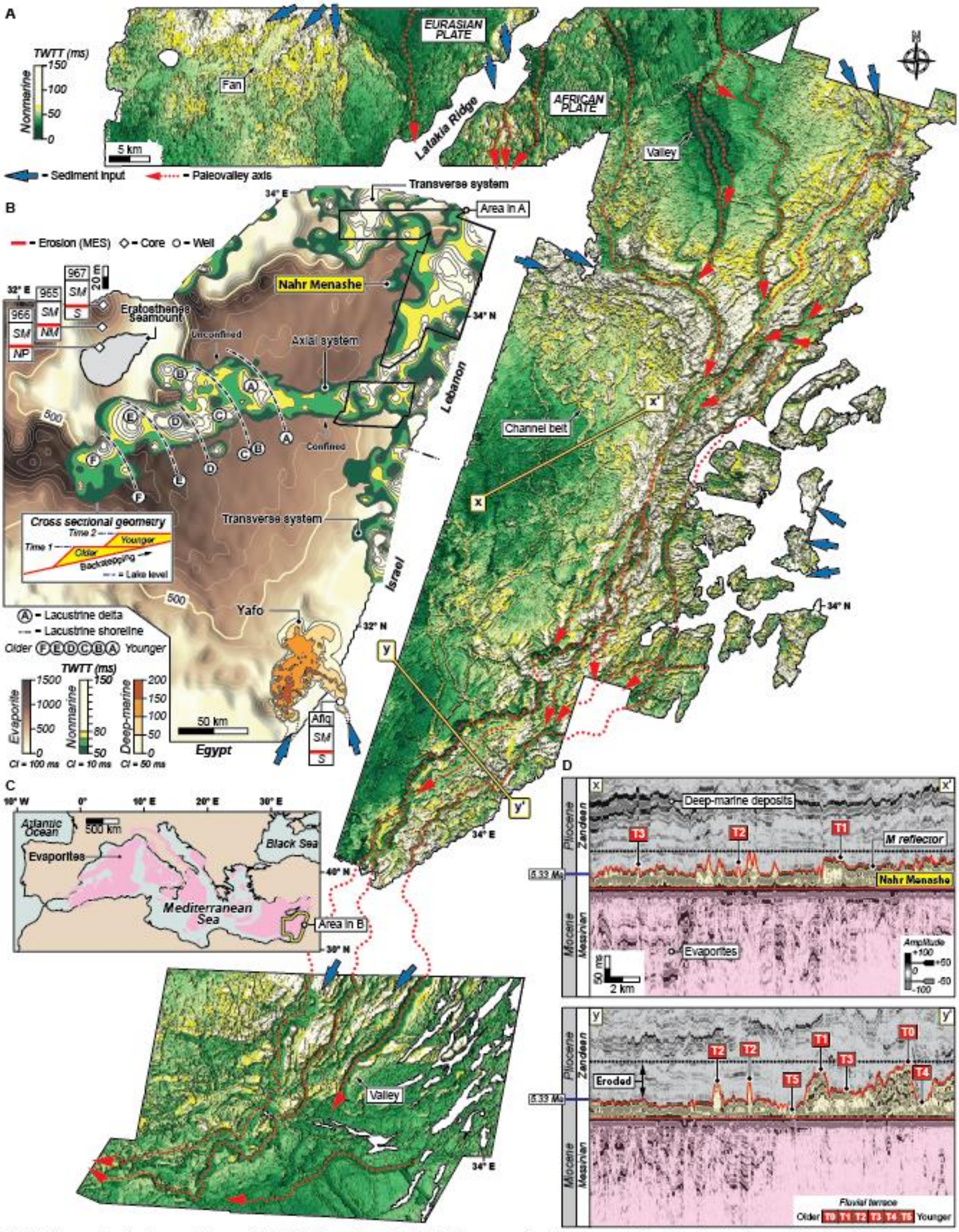
The late Miocene Messinian salinity crisis (MSC) was a major oceanographic event that led to widespread evaporitic accumulation throughout the Mediterranean basin. Multiple hypotheses have emerged regarding the origin of marginal and basin-centered evaporitic and post-evaporitic MSC accumulations, with interpretations ranging from fully subaqueous to subaerial. Here, we introduce a vast and previously unknown upper Messinian fluvio-deltaic complex, termed the Nahr Menashe, which was deposited in the eastern Mediterranean (offshore Lebanon, Israel, and Cyprus). The southwest-oriented system directly overlies Messinian evaporites, was comparable in size to the late Miocene Nile River (>2,500 km^3 in volume), and was sourced from northern Syria and/or southern Turkey. The Nahr Menashe consists of unusually well-preserved and continuous nonmarine seismic facies traceable over distances >350 km (along dip), which transition from updip fluvial systems into six downdip and backstepping lacustrine deltaic lobes. When combined with features interpreted as paleo-lacustrine shorelines, we conclude that sea-level drawdown during the MSC resulted in a subaerially exposed Levant basin prior to the 'Lago Mare' final MSC Zanclean transgression. Our study uses a newly discovered late Miocene fluvio-lacustrine complex to open new avenues for modelling source-to-sink budgets and sediment provenance in the eastern Mediterranean, and fundamentally changes our perception of drainage and active deformational in the eastern Mediterranean.



Distribution and seismic morphology of the Nahr Menashe unit. (A) Thickness map (isochron) created from 3D seismic volumes, showing Messinian evaporites, Messinian erosional surfaces (MES), and south- to southwest-oriented fluvial deposits of the Nahr Menashe unit, which consists of fans, channel-belts, and paleovalleys. TWTT = two-way travel time. (B) Isochron created from 2D seismic lines showing extent of Nahr Menashe deposition, including six fluviodeltaic lobes (A-F). Interpretation of core (ODP 965-967) and well (Afiq) data: SM = shallow marine; NM = nonmarine; S = salina; NP = not present. CI = contour interval. The lower Pliocene Yafo Sand Member is a remobilized deep-marine fan system. (C) Location map, illustrating eastern Mediterranean study area. (D) Vertical seismic sections flattened on top Messinian evaporites illustrate fluvial terrace development, erosion, and topographic inversion of the Nahr Menashe unit. Seismic data courtesy of PGS.

NOTES:

Reservoir Characterisation of the Plio-Pleistocene Deep-Marine Sediments of the Nile Delta, Egypt

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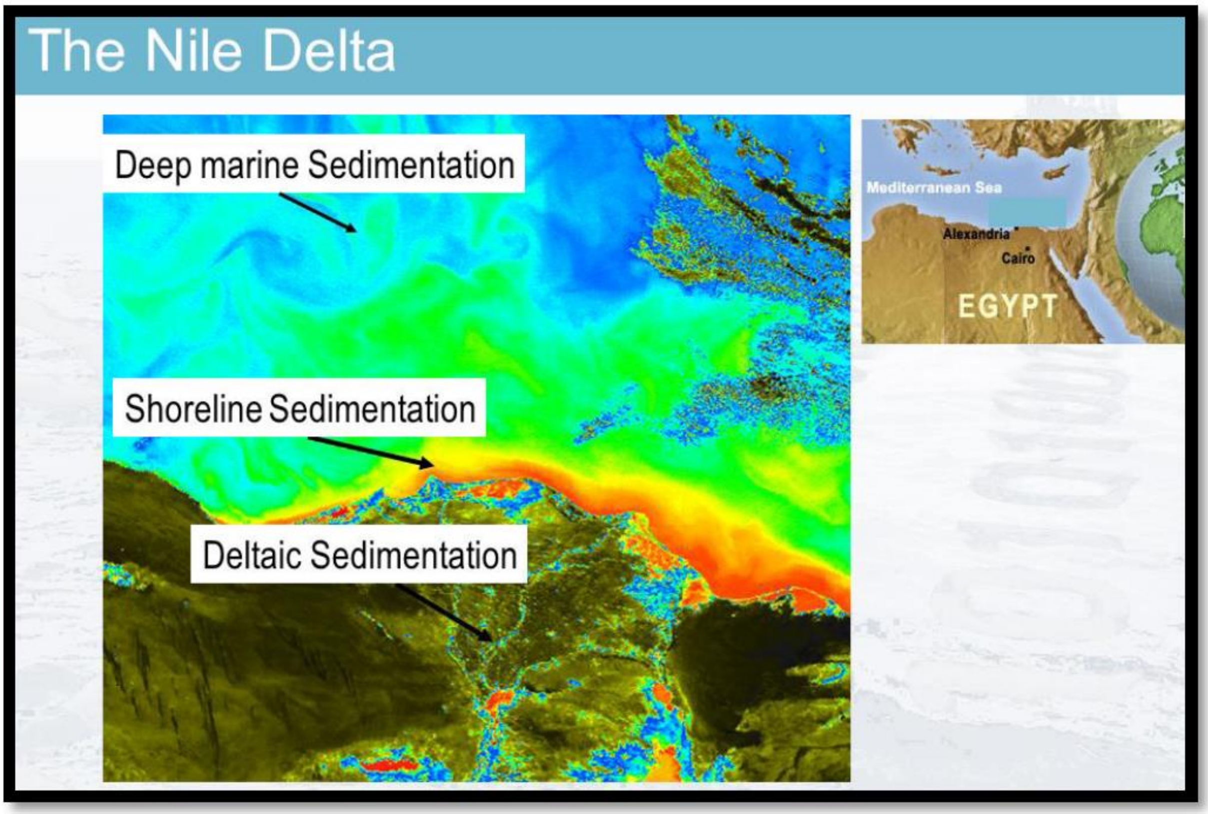
Principal Geologist, Geode-Energy Ltd

The Plio-Pleistocene succession is a primary target for hydrocarbon exploration in the West Delta Deep Marine concession, East Mediterranean. The Pliocene Nile Delta Petroleum system comprises turbidite fans and channels. A detailed lithostratigraphic and sedimentological approach has proved a good basis for a regional correlation scheme, capable of predicting lateral facies variations. Excellent reservoir distribution is mainly linked to the relative sea level low stands, where sands were conveyed to the outer belts through major incised canyons in the southern platform to distributary and submarine channels. During the late Pliocene and Pleistocene, the Nile Delta prograded rapidly northwards. Major tectonic elements like Rosetta and Temsah faults have largely affected the depositional system and offered local accommodation for sand entrapment. A pronounced highstand marked the onset of the Pliocene delta and fluvio/deltaic sediments of the Abu Madi and Rosetta Formations.

Throughout the Pliocene, the southern area of the deep-water block was characterized by North-South linear turbidite channels, but towards the West, the platform boundary fault marks a transition from channels to sand sheets. The pods/sand sheets were deposited in a lower slope/toe of slope and basin plain settings. These sheets possess an excellent reservoir character but need a good structural trap integrity to retain hydrocarbon.

The northwestern portion of the Nile delta is characterized by an amalgamated complex of leveed channels. These channels and channel complexes can be up to five km wide and extend in northwestern direction. The facies within the channels and the sand sheets can appear similar, making the two geometries difficult to differentiate. However, it has been observed that subtle differences in the dip and facies can delineate the two types of sands.

The Nile delta deep marine sediments are characterized by large scale slumps, which are distinguished by seismically resolvable surfaces and internal geometries. These slumps are regional and cover large areas of slope and basin floor and represent distinct stratigraphic units in the Upper Pliocene- Pleistocene section.



NOTES:

Wednesday 30th May 2018
Session Four: Carbonates

KEYNOTE: Seismic stratigraphy, evolution and regional context of carbonate platforms on the southern margin of the Eratosthenes High, eastern Mediterranean

Trevor Burchette[1], Gavrielle Groves –Gidney[2], Kul Karcz[3]
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3D seismic over the south-eastern margin of the Eratosthenes High in the Cyprus Exclusive Economic Zone, eastern Mediterranean Sea, has provided new insight into the origin and evolution of this prominent feature. The data show two significant and fundamentally different carbonate platforms overlying an extensional basement. Seismic stratigraphic interpretation, correlation, and comparison with regional geological analogues suggest that the older of these is of Jurassic to Cretaceous age and the younger one of later Cretaceous or Tertiary age. Together they build a succession up to c. 2200 m in thickness. Both platforms are overlain by blanketing intervals of parallel seismic facies, probably representing pelagic or hemipelagic deposits. The older Mesozoic carbonate platform exhibits a uniform, layered stratigraphy over the whole of the area, but thickens gently south-eastwards towards the steep, truncated edge of Eratosthenes in response to flexural subsidence. The younger platform, in contrast, developed an extremely complex stratigraphy comprising multiple high-frequency sequences, the geometries of which were controlled by a combination of small-scale relative sea-level variations, structural movement and substrate collapse at several scales. The younger platform forms a linear, partly-detached trend paralleling the south-eastern margin of the high for over 60 km. The outer margin of this platform became pinned to a structural break in slope, while the inner margin prograded for over 30 km towards the interior of the high with relatively little aggradation, infilling an interior basin up to 200 m deep created largely by platform growth. The older platform is truncated at the margin of the high and dissected by deep-seated faults. These transect the entire stratigraphy, possibly up to the early Messinian, and form complex corridors of subsidence in the shallower section. The resultant northwest-southeast orientated linear troughs formed synsedimentary growth structures into which the younger platform prograded. Collapse of underlying karst may have accentuated this process. Subsidence over these features also locally affects the present sea floor. Following protracted termination of the younger platform, Messinian evaporites were thrust up onto the margin of Eratosthenes, locally scouring the underlying stratigraphy. Depression of the margin of the high, with concomitant tilting of both platforms towards the southeast, appears to have been contemporaneous with arrival of Eratosthenes at the Cyprus subduction zone in the Plio-Pleistocene and overthrust of the Messinian evaporites. "Back-stripping" this event using either of the flat platform surfaces as a datum provides useful insight into the deeper structure and stratigraphy of the Eratosthenes High.

NOTES:

Isolated Carbonate Platforms of the Mediterranean Region: Geological Features and Hydrocarbon Potential of an Attractive Exploration Target

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The outstanding recent gas discoveries in the East Mediterranean demonstrates that the potential of Isolated Carbonate Platforms (ICPs) in the region has been underestimated during past exploration efforts. The discovery of a major gas field at Zohr by Eni in Egyptian waters in 2015 demonstrated the potential importance of these systems as hydrocarbon reservoirs and the recent discovery of Calypso confirms the widespread distribution of this promising play.

The question is now: where are similar carbonate structures hidden in the Mediterranean and what do they contain? What do these carbonate structures still conceal? Little is known about these structures from subsurface data. Their depositional architecture and reservoir distribution can be frequently hard to predict in a reliable way through seismic data only. Moreover, the scarcity of subsurface case histories in the Mediterranean Region creates an urgent need for surface and subsurface analogues to enable a better assessment of these targets through geometrical, stratigraphic and sedimentological analysis.

Several surface and subsurface examples from the Mediterranean Region show that many ICPs nucleated on top of fault-bounded structural highs formed by differential subsidence resulting from the rifting that affected Tethyan margins during the early Mesozoic. The geomorphic relief of ICPs resulted from long-term platform aggradation and the stacking of individual units during postrift thermal subsidence. The demise of ICPs is related to paleoceanographic events or the development of compressional belts around the basin. Their size, geometric and sedimentary characteristics depend on the complex interaction between regional to global processes and the productive ability of the active carbonate factories, which vary over time and with paleolatitude, under the continuous influence of climate changes and environmental perturbations, producing effects that vary between, sometimes even within, platforms.

This study reviews the characteristics of several Meso-Cenozoic ICPs of the Mediterranean Region from outcrop and subsurface data, including examples from the Mediterranean. The study defines criteria that enable the identification of ICPs in the Mediterranean Region, the processes that control their initiation and development, their paleogeographic distribution and allows a comparison of size, geometries, depositional architectures, types of carbonate factories that characterize ICPs in the Mediterranean Region with the aim of increasing the efficiency of both exploration and development of these attractive targets.

NOTES:

Cretaceous reservoirs of the Eastern Mediterranean: hunting for analogues in the Mediterranean Region

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The Zohr and Calypso gas fields in the Levantine Sea developed on structural highs connected to the Eratosthenes Seamount crustal block and are characterized by geometries typical of a shallow-water isolated carbonate platforms, immediately lying below the Messinian Salt. The reservoir is formed by a very thick sequence of Cretaceous platform carbonates, opening a completely new play concept focused on high-relief isolated carbonate platforms.

This study focuses on the review of the characteristics of all the Cretaceous carbonate platforms to understand the main controlling factors for their development and similarities with the Eastern Mediterranean HC discoveries.

In the Mediterranean area and surrounding regions, the Cretaceous shallow-water carbonates have always been one of the main target for oil and gas exploration. The majority of the discoveries are located in the Central and Western Mediterranean, while in the Eastern Mediterranean the exploration activity connected to Cretaceous carbonates targets is less developed.

Shallow-water carbonates of Cretaceous age are one of the main HC targets in Apulian Platform (Italy), Sirte basin (Libya) and offshore Spain, but also in onshore and offshore, Tunisia and in the Western Desert basin of Egypt. A small field occurs in the Levant Platform between Israel and Egypt and some oil shows have been recorded in the Adriatic Platform in Croatia.

Cretaceous shallow water carbonates are widespread in the Peri-Mediterranean region, where they developed in wide carbonate platform settings separated by deep-water basins. These units deposited in the Mesozoic Tethys before or just at the beginning of the Alpine deformation phase that involved these sequences and gave rise to the present-day setting of the region. The characteristics of the Cretaceous carbonates are extremely variable and strongly controlled by the tectonic deformation and eustatic fluctuations occurred during a “greenhouse” period. The Cretaceous environment was influenced by accelerated break up of Pangaea during Early Cretaceous, associated with the formation of a multitude of rift basins, intensified spreading, and important volcanic activity on land and in the sea.

Whereas, the more isolated carbonate platforms showed more or less continuous and predominant carbonate deposition, usually persisted since the Jurassic, different lithologies and depositional processes characterized the attached platform from Lower to Upper Cretaceous.

During Early Cretaceous, the attached platforms of present-day Northern Africa and Mediterranean Middle East were subject to high siliciclastic input due to their proximity to emerged lands. When the erosion rates were intense, the siliciclastics drowned carbonate platforms and were bypassed into the basin along the margin, especially in the offshore North Sinai and Western Desert.

The widespread transgression occurred at late Lower Cretaceous and throughout the Upper Cretaceous (from Aptian/Cenomanian onwards) led to the deposition of predominant carbonates in these attached platforms.

Our studies highlight the occurrence of two different type of margins in the Cretaceous platforms, which can be found in several locations of the Periadriatic area, like in the Maiella Mountain (Apulian Platform, Central Apennines), in the Monte Cavallo area (Adriatic Platform, Southern Alps) and also in the subsurface Adriatic Offshore (e.g. Medusa).

The Periadriatic carbonate platforms were characterized, during Lower Cretaceous, by predominant mud-supported lithologies that originated a flat-topped shelf geometry, with a tectonically-controlled by-pass steep slope and without a proper bioconstructed margin. The mud produced in the inner platform was exported to the basin but was not able to form a real slope. Consequently, the platform-derived material that was able to reach the basin was almost absent and the basinal sequences, fed only by carbonate-mud shedding, were extremely thin and condensate. In the Upper Cretaceous, the sedimentation locally switched to a bioclastic carbonate factory shedding huge volumes of calcarenites in the surrounding basins, that, combined with a strong decrease in subsidence, developed a slope that later evolved into a ramp.

The best analogues of the Eastern Mediterranean carbonate discoveries are the isolated platforms that occur in subsurface in the Adriatic and Ionian Seas (Barbara Platform in offshore Italy/Croatia, A4-1X and nearby buildups of Albanian offshore) in Cephalonia Island of Greece, in the Tunisian offshore (Isis, Miskar and others) and in the Italian onshore (Bagnolo platform), with proved oil and strong similarities with Zohr in terms of size, age and characteristics.

Despite the similarities between the selected analogues and the Eastern Mediterranean HC discoveries it is clear that differences exist, because the depositional profile of these platforms, their internal architecture and their facies heterogeneities are the result of a complex interplay between global and local effects, as production and reworking processes, different accommodation, sea level oscillations, paleoceanographic and paleoclimatic changes, trophic resources distribution and biological evolution and the interaction with tectonic and thermal subsidence.

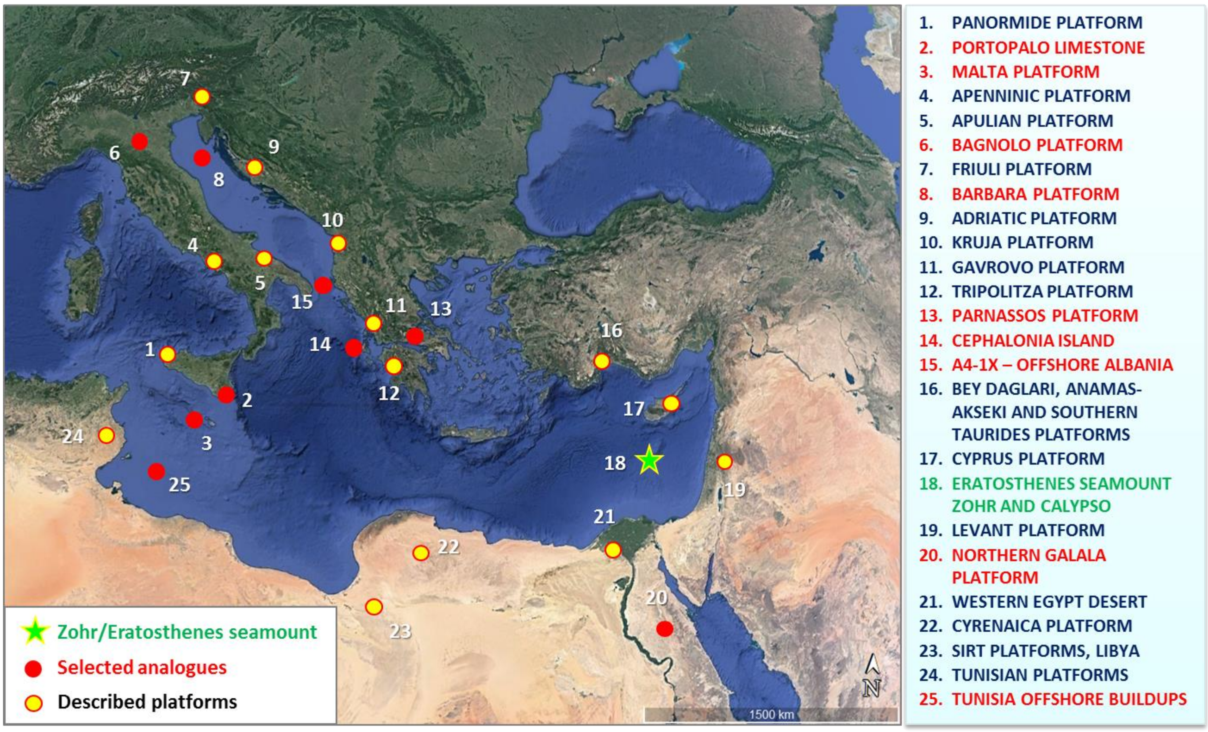

Figure1. Shallow water carbonate domains of Cretaceous age in Central and Eastern Mediterranean and selection of the potential Zohr and Eratosthenes analogues (basemap from Google Earth).

NOTES:

Deep-water bottom currents deposits from the Lefkara and Pakhna formations (Cyprus): conceptual and economic implications

F.J. Hernandez-Molina[1], H. Huneke[2], F.J. Rodriguez-Tovar[3], E. Llave[4], Z.L. Ng[1], Chiarella, D.[1], S. Suklap[1], B., Docherty[1], L. Hyslop[1], A., Mena[5], D.A.V. Stow[6]
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One of the best examples described in the literature on ancient bottom current deposits is from the Eocene to the early Miocene deposits in the Lefkara and Pakhna formations (Cyprus). During the last four years *The Drifters Research Group* has been studying these deposits in order to understand the sequence of sedimentary facies and for its comparison with analogue deposits in modern / recent deep-water environments. Field campaigns have been realised for the identification of the best outcrops, realising sedimentary logs, and sedimentary and ichnological analysis. Moreover, thin section analysis under the petrological miscroscope, direct and indirect measurement of porosity, scanning electron microscopy (SEM) for element compound and X-ray diffraction (XRD) for mineral compounds have been executed. The chronological framework was based on micropalaeontology with planktonic and benthic foraminifera and nannofossils, improving the age-estimates of the sediments on the studied sections compare with previously ages. The dominant sedimentary facies are characterised by calcarenites, chalks, cherts, marls and calcilutites which can be interpreted as contourites, turbidites, reworked turbidites, and hemipelagic and pelagic deposits deposited in a continental slope setting. Sandy contourites beds are identified in three main packages and although digenetic processes have been intense, parallel lamination, cross-lamination, banding, flaser structures and dune-like geometries have been identified. The porosity values on these deposits excess of 10% and bioturbation is high throughout denoting a general shallowing upward trend in the sequences. These preliminary results reveal that microfacies, ichnological features and sedimentary structures could be good diagnostic criteria for sandy contourites determination. Their characteristics in the studied outcrops are very common in modern deep-water sedimentary environments (e.g., contourite terraces) and they are of great scientific and economic significance, but further research work is needed for their better understanding and distinction from other deep-sea deposits.

NOTES:

Wednesday 30th May 2018
Session Five: Regional and Messinian

The tectonic evolution of the eastern Levant Margin

GHALAYINI, R. [1]
[1]*Exploration Consultant, Ministry of Energy and water Lebanon*

The Eastern Levant margin offshore Lebanon exhibits a complex deformation history in relation with the regional geodynamic evolution and with the activity of the adjacent Levant Fracture System (LFS). This contribution presents a new interpretation of this margin offshore Lebanon and sheds more light on its geodynamic evolution based on geophysical data and structural modelling.

The Levant margin is characterized today by a broad platform offshore Lebanon, separated into a northern and southern parts based on crustal differences. The southern part, is referred to as the Saida-Tyr plateau (STP). It is bordered by large crustal faults to its north and west, separating it from the deep Levant basin. Geophysical data indicate the presence of strong gravity anomalies below this plateau together with elevated Mesozoic units relative to the remainder of the basin. This could indicate that the STP is underlain by a crust of a different type than that of the basin and could be similar to that of Eratosthenes. The northern part, however, consists of a broad Mesozoic platform floored by a thinned continental crust. It is not bordered by crustal faults such as the southern margin. Triassic extensional structures are observed in the north and are oriented NNW-SSE, probably due to counter-clockwise rotations in the Lebanese segment. The tectono-stratigraphy of the eastern Levant Margin has been constrained by seismic and well data

A set of complex ENE trending dextral strike-slip faults are documented along the eastern Levant margin, and are observed particularly on-and offshore Lebanon. These faults are most likely inherited from the lower Cretaceous subsidence and extension documented in the Levant, have been reactivated in the Late Miocene, and are still active today. Their activity and evolution is directly linked to the evolution of the LFS and the interaction between Arabia and Africa. Such tectonic activity has affected the regional stress-field which in turn has been responsible for the reactivation of the margin’s structures as of the late Miocene to recent times. In addition, the rheological contrasts from south to north, observed in particular along the intersection with the Palmyrides trend, could have had an important effect on the amplitude of reactivation, geometry and type of reactivated structures. As such, we show evidence that the location of the plate boundary, the LFS, has been preferentially localized based on crustal heterogeneities and pre-existing structures. In addition, we provide evidence for at least 80 km of displacement at the central Lebanese segment of the LFS, therefore negating any missing displacement along the path of the LFS.

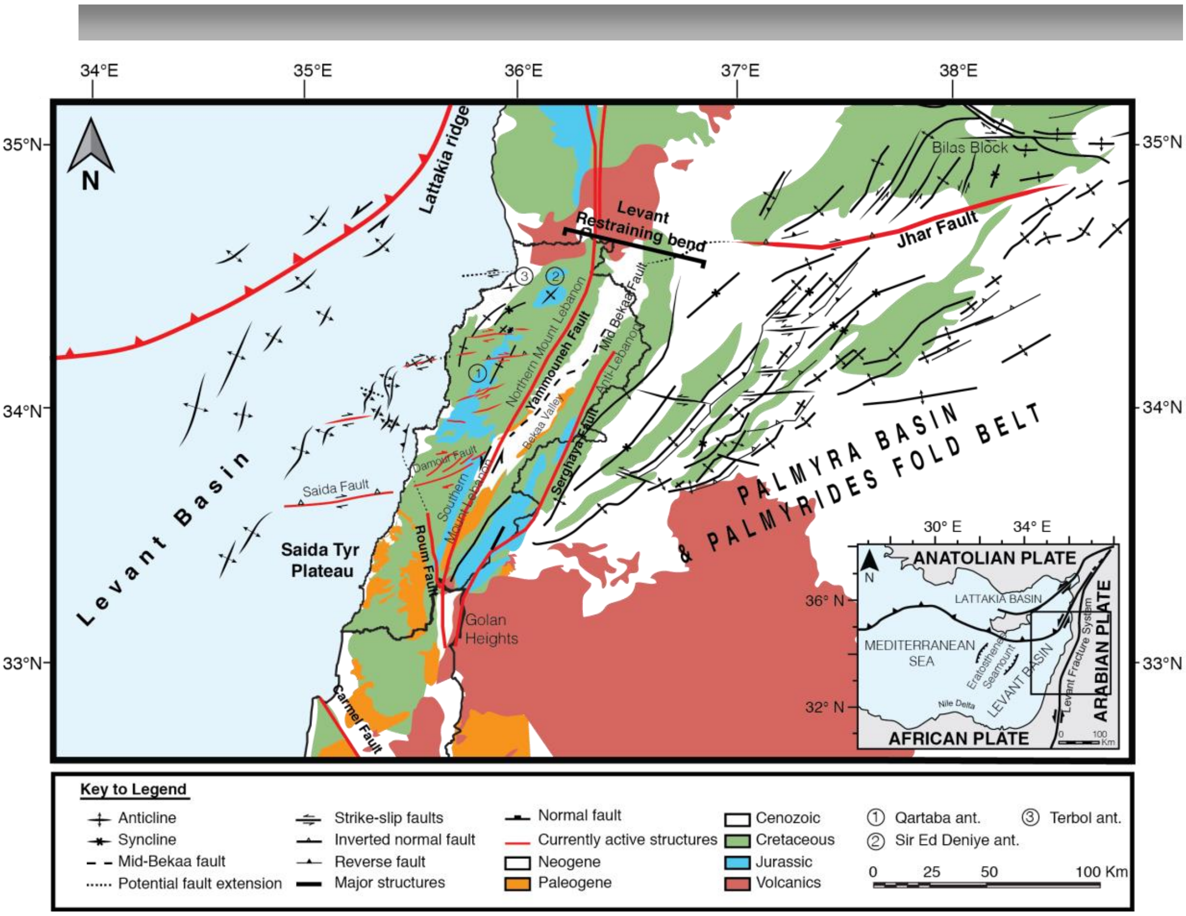


Figure showing the structures of the eastern Levant margin in Lebanon. The passage of the LFS plate boundary was most probably affected by the presence of the Palmyrides structure. Note that the Jhar and the Saida fault are separated by about 80 km and are thought to consist of a single and continuous structure prior to the LFS development.

NOTES:

Intrasalt structure and strain partitioning in layered evaporites: insights from the Messinian salt in the eastern Mediterranean

Sian Evans[1], Christopher A.-L. Jackson[1]
[1]Basins Research Group (BRG), Department of Earth Science & Engineering, Imperial College, Prince Consort Road, London SW7 2BP.

Evaporite-dominated units are lithologically heterogeneous as halite is interbedded with other salts, in addition to clastics or carbonates. This lithological heterogeneity can lead to rheological heterogeneity, and the different mechanical properties of the various rock types controlling strain partitioning within deforming evaporites. Determining the composition and internal structure of salt bodies is important for safe drilling through thick salt sequences, and enables us to build better velocity models that allow more accurate seismic imaging of subsalt geology. However, due to typically poor seismic imaging, and a lack of outcrop and well data, the nature of this lithological control on intrasalt deformation is poorly understood.

Heterogeneous, highly reflective, Messinian evaporites, which are shallowly buried and only weakly deformed, occur along the Levant Margin in the eastern Mediterranean. This provides us with a unique opportunity to assess how: (i) intrasalt strain varies within thick salt during the early phase of margin development; and (ii) in the context of the Eastern Mediterranean, how the intrasalt seismic-stratigraphic architecture links to the geodynamic context and evolution of this tectonically complex region.

Previous studies of the Messinian salt in the eastern Mediterranean have observed increasing strain toward the top salt, before an abrupt reduction in the overburden. The strong, competent layers embedded within the halite deform in a brittle manner, while weak, incompetent halite beds deform in a ductile manner. As the more competent beds in the evaporitic sequence are folded and faulted, multiple detachment levels develop in the encasing weaker layers. It follows that the lithological sequence exerts a control on the strain distribution within the evaporite unit as it deforms in response to gravity gliding and spreading.

We use high-quality 2D and 3D seismic reflection data to map intrasalt structural style, and horizontal and vertical variations in strain. This enables us to determine how lithological and thus mechanical heterogeneity affects the structural evolution of the salt during early stage salt tectonics. Given that salt tectonics dominates the structural development of salt-influenced rifts and passive margins, the results of this study have implications for the development of structural and stratigraphic traps in these settings.

NOTES:

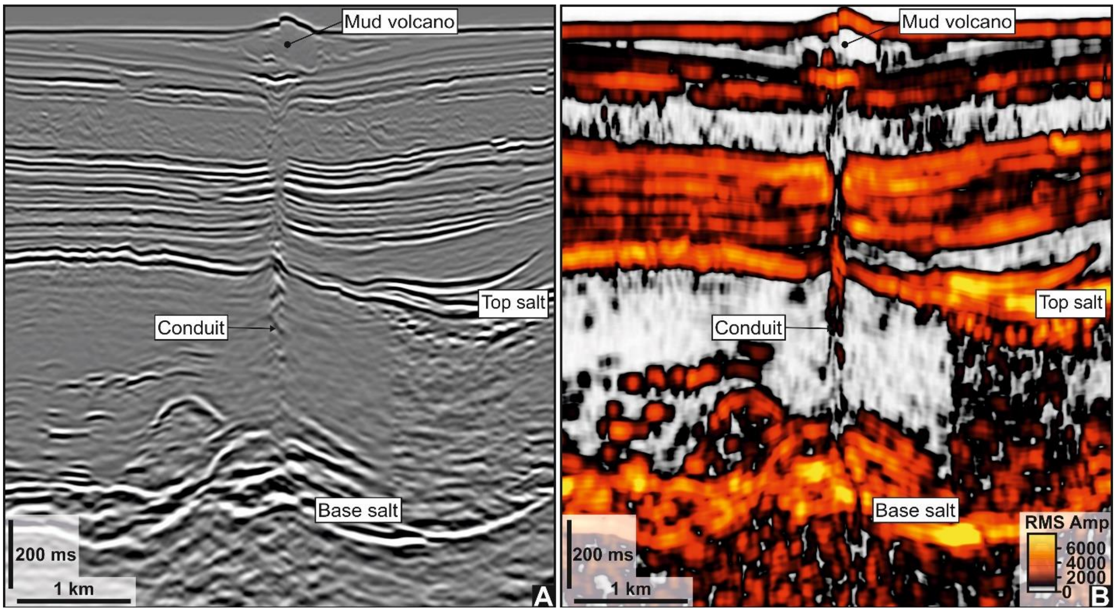
Bypassing of the thick Messinian evaporites in one the most prolific mud volcano provinces on Earth

Christopher Kirkham[1], Joe Cartwright[1], Christian Hermanrud [2], Christopher Jebsen [3]
[1] Department of Earth Sciences, University of Oxford, South Parks Road, Oxford, UK
[2] Statoil ASA, N-7005 Trondheim, Norway
[3] Statoil, N4032 Stavanger, Norway

We present a study from the western Nile Cone on one of the most prolific mud volcano provinces on Earth. In this region as many as 386 mud volcanoes have been identified to have erupted at numerous intervals over the last 5.3 Myrs since the end of the Messinian Salinity Crisis. The majority of these mud volcanoes are buried (276), yet the region has remained highly active in recent times with as many as 110 mud volcanoes visible at the present day seafloor. The identification of pre-salt depletion zones underlying the mud volcanoes combined with documented core samples from extruded edifices at the seafloor in this region present a strong argument for a pre-salt primary source of mud likely Tortonian in age.

The conduits that feed these mud volcanoes are interpreted to transect the >1000-m-thick Messinian Evaporite succession, demonstrating that the eruptive process is sufficiently dynamic to breach the formidable seal represented by the evaporites. The mud volcano conduits are remarkably similar in geometry and seismic characteristics to many previously described examples of fluid escape pipes. Similar to fluid escape pipes these mud volcano conduits are formed via hydraulic fracturing driven by high overpressures that developed in the pre-salt source stratigraphy.

This demonstrates the potential in regions of the Mediterranean for catastrophic bypassing of the thick unit of sealing evaporites several hundred times via focused fluid and sediment mobilisation. Although in many parts of the Mediterranean the salt acts as a good seal it is clear that very high overpressures can develop in pre-salt layers and under exceptional circumstances can compromise the integrity of the 'sealing' unit. Prolonged mud volcanism and repetitive bypassing of the thick evaporite sequence over the last ~5.3 Ma demonstrates the potential for sustained pre-salt overpressure in parts of the Mediterranean or for the recharge of overpressure over several hundreds of thousands of years via a mechanism such as hydrocarbon generation. Both mechanisms imply the possibility of continued mud volcanism in this region and for a significant drilling hazards associated with pre-salt overpressure in the Mediterranean.



A mud volcano conduit bypassing a thick sequence of Messinian evaporites. A) A seismic profile through a mud volcano and mud volcano conduit. The conduit is clearly imaged transecting the Messinian Evaporite succession above a base-salt crest and the post-salt sequence to the base of a mud volcano that is visible at the present day seafloor. B) An RMS amplitude profile that displays the mud volcano conduit as a vertical zone of relative low amplitude in the post-salt sequence and as a vertical zone of relative high amplitude in the Messinian evaporites.

NOTES:

Poster Presentation Abstracts

The upper Cretaceous palaeo-slope transition: an integrated calcareous nannofossil and microfacies approach (Ionian Islands, Preapulian Zone, Western Greece)

Ioulietta Mikellidou[1], Maria V. Triantaphyllou[1], Stefano Patruno[2], Fotini Pomoni-Papaioannou[1], Vasileios Karakitsios[1]
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The Ionian islands are situated on the west part of the Hellenic Arc, part of the most active plate margins in the Mediterranean.
The westerly-verging Hellenides fold-and-thrust belt in this area comprises the deformed Meso-Cenozoic basinal succession of the Ionian Zone, which thrusts over the time equivalent slope unit of the Preapulian Zone. The basal front of this tectonic contact outcrops along the eastern edges of Kefalonia and Zakynthos islands.
Furthermore, the palaeoenvironmental transition between the Late Cretaceous persistent carbonate platform 'Apulian' facies and the time-equivalent 'Pre-Apulian' facies is exposed on the islands of Zakynthos and Kefalonia. Nannoflora analyses are conducted for the first time, providing detail dating of the outcropping Cretaceous strata in these two islands. Also, microfacies are investigated in order to appreciate the changes of palaeoenvironments during the Late Cretaceous.
Thick-bedded calcareous strata outcrop on the westernmost edges of the island, and contain microfacies and microfossil assemblages characteristic of the edges of Cretaceous carbonate platforms, including rudists in life position. The remainders of the Cretaceous outcrops are composed by slope facies, comprising an intercalation between thin-bedded, fine-grained pelagic calcareous strata and thicker-bedded and coarser-grained depositional events. The latter can be sub-divided into massive megabreccias strata, dominated by near platform microfacies (wackestone-packestone) and thinner-bedded calciturbidites, which are composed by a mixture of pelagic microfacies and re-transported neritic assemblages.
Most of the samples proved barren of calcareous nannofossils, perhaps due to an intense diagenetic and tectonic history. However, a section to the south of the island of Zakynthos (Lithakia-Agalas) was both continuous and relatively prolific. In the investigated section, strata form a north-east dipping monocline, spanning the transition from the edge of the Apulian platform (to the westernmost edges) and the Pre-Apulian slope facies. Calcareous nannofossil assemblages are dominated by Watznaueria barnesae, Quadrum garneri and Retecapsa crenulata. Campanian-Maastrichtian markers such as Reinhardtites levis, Quadrum trifidum, Broinsonia parca [range: UC15e (72.05Ma)-UC14 (81.43Ma)] occur in the central and eastern part of the island, indicating a Campanian-Maastrichtian age. Older nannofossil assemblages were logged in the westernmost part of the study section. The sediments are either lower Late Cretaceous strata revealed to the west of the section because of the geometry (consistent with the dip of the strata) and/or represent the contribution of older material eroded from the edge of the platform and re-deposited on a proximal slope area.
The only other sampled sections containing nannofossils are in the northern part of the island, around the village of Orthonies. Here, a typical slope succession (alternations between thinner-bedded more pelagic strata and thicker-bedded re-sedimented deposits) are characterized by poor nannofossil assemblages. This succession is not older than Turonian, as suggested by the occurrence of Micula staurophora, and the oldest part of the section is not younger than Early Campanian, as indicated by the presence of Lithastrinus grilli [range: Early Campanian to Late Coniacian; UC15d (75.93Ma)-UC11 (86.50Ma)]
More generally, the whole Zakynthos was previously thought to belong to the transitional Pre-Apulian (=Paxos) unit. Our analyses, however, show that towards the westernmost part of the island, Cretaceous platform margin facies possibly attributable to the Apulian Platform are present, with a gradual transition to uppermost Cretaceous Pre-Apulian facies towards the east.
The final aim is to reconstruct the position of the Apulian platform edge in western Greece, which may have signicant implications in oil exploration.

Developing Regional Tectonostratigraphic Models for Hydrocarbon System Evaluation in the External Dinarides and Hellenides

Toro, B.*[1], Palotai, M.[1], Vincent, S.J.[1] and Vautravers, B.[1]
[1] *CASP, Madingley Rise, Madingley Road, Cambridge, CB3 0UD, United Kingdom*

The Dinarides – Hellenides are a southwest verging orogenic belt that has resulted from the subduction of two branches of the Neotethys Ocean and the continental lithosphere of Adria beneath Eurasia.

Hydrocarbon production and/or field development in Albania, Croatia and Greece, as well as analogues in Italy, prove the existence of multiple petroleum systems in the region. However, differing geological traditions across the several countries on the eastern side of the Adriatic Sea mean that coherent tectonic and stratigraphic models are lacking.

In this contribution we present findings of a literature-based review into the geodynamic setting and tectonic evolution, pre-flysch stratigraphy and petroleum system elements, structural styles of the external Dinarides and Hellenides, and flysch provenance. Emphasis is placed on the regional understanding of hydrocarbon systems and their tectonic and stratigraphic framework. Syn-orogenic sediments act as regional seals above fractured carbonates as well as reservoirs. Their facies distribution and provenance are strongly linked with the tectonic evolution of the region as well as changes in source regions in the hinterland.

The results of ongoing targeted structural geological and sedimentological field work, investigating the above mentioned topics, will also be presented.

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Straight out door and walk around to the Courtyard.

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All accidents should be reported to Reception and First Aid assistance will be provided if necessary.

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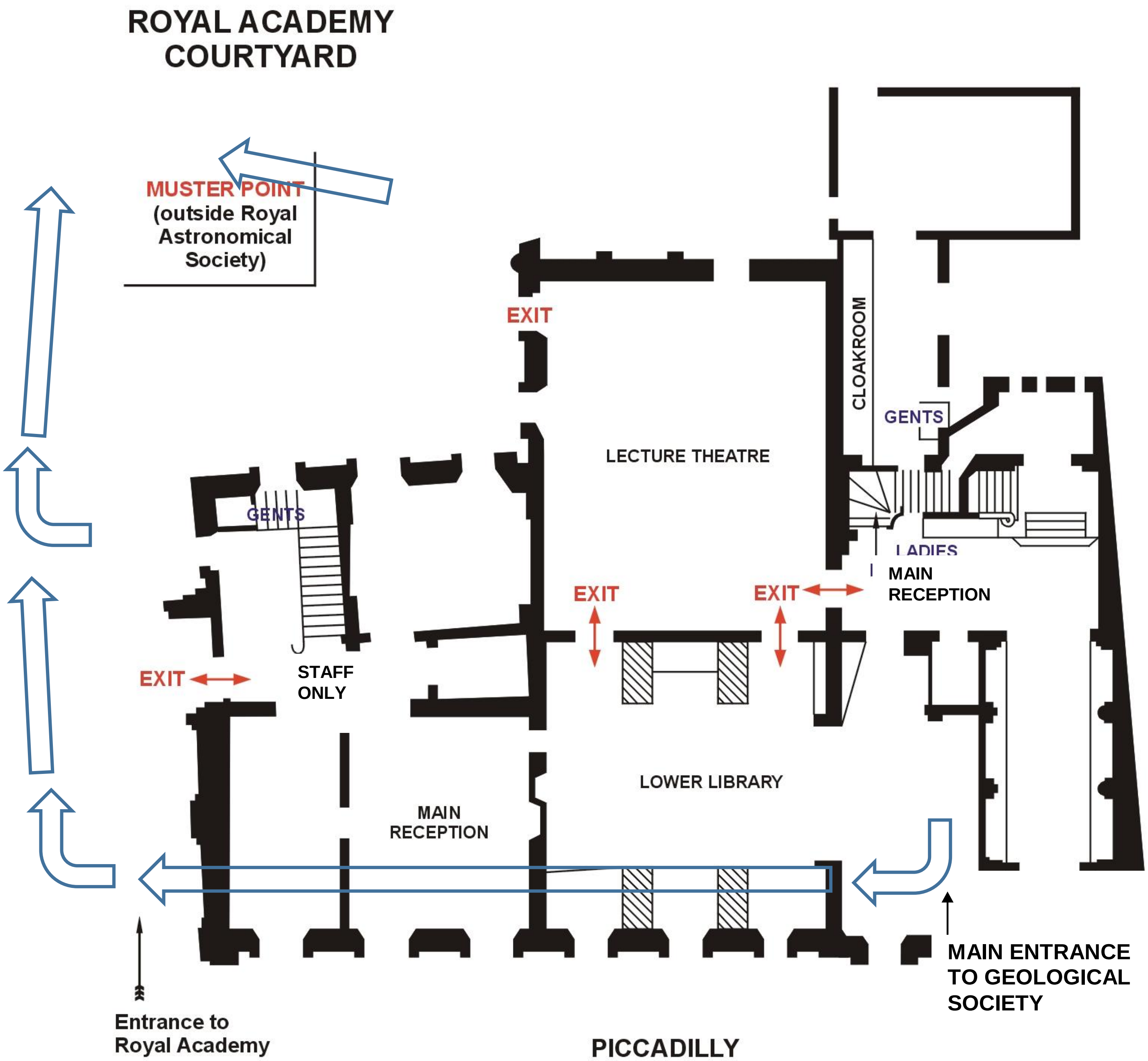
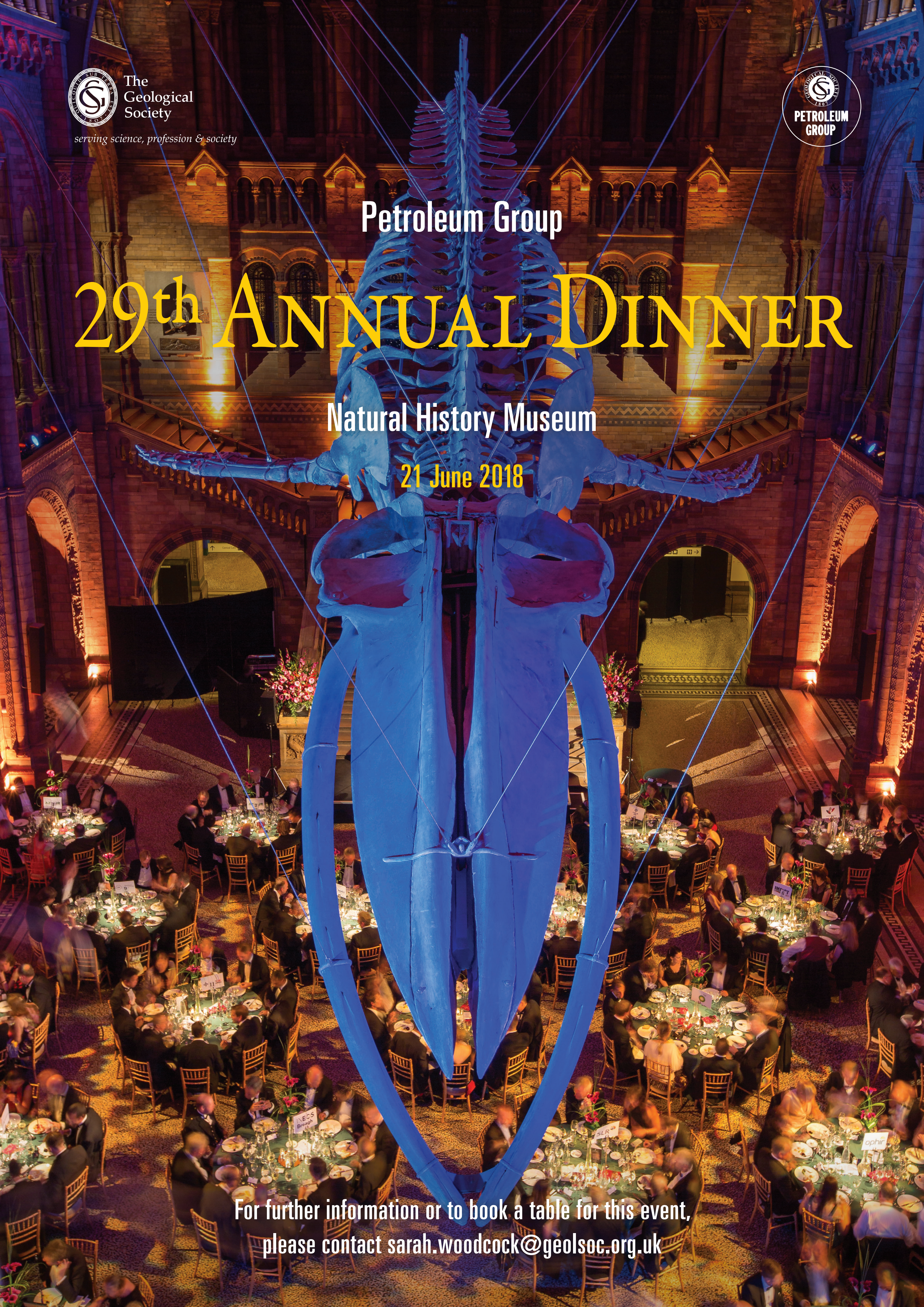
Ground Floor Plan of the Geological Society, Burlington House, Piccadilly

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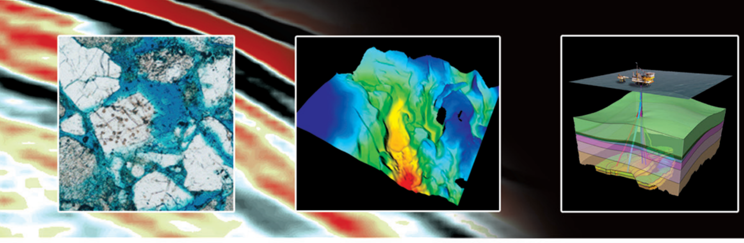

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Communicating Geoscience: Building Public Interest and Promoting Inclusive Dialogue

4 September 2018

The Geological Society, Burlington House, Piccadilly, London

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Heriot-Watt University

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Sound Energy Plc

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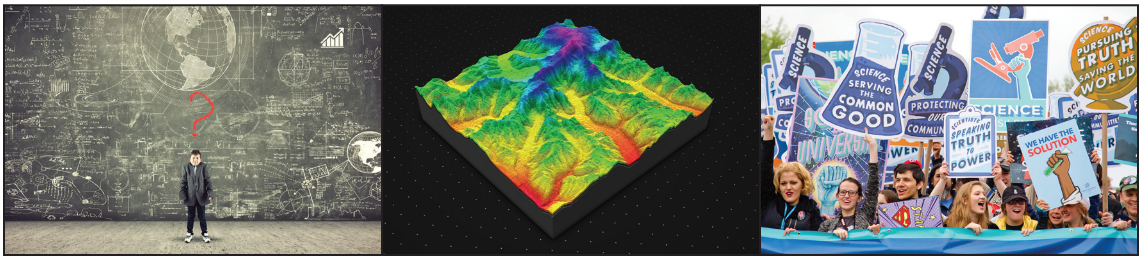

Engaging with the public to communicate geoscience can be fraught with difficulties, with explanations of complex subsurface concepts and the use of scientific terminology often alienating those we seek to engage with. This is especially true in communication from the energy industry regarding its activities, products and role in society, which can inspire a passionate and often polarised reaction.

There is often mistrust towards science and a bias towards industry, including those working in academia who undertake industry-funded research. Accompanying this is the targeted manipulation of fact and theory, which has led to the rise of “fake news” and a greater scrutiny of both business and individual interests. While this can make science communication challenging and frustrating, engaging with the public can be rewarding and is a key tool to build trust, dispel myths and provide up-to-date scientific knowledge to the public.

This one-day conference aims to look in-depth at geoscience communication in the energy industry to better achieve effective public engagement. This includes evaluating lessons learned from case studies, establishing best practice and understanding the value and importance of public perception. Speakers have been invited from both industry and academia and represent a range of disciplines, including oil & gas exploration, carbon capture & storage, shale gas, geothermal energy and social science.

To further explore themes of communication, we plan to live stream sessions to virtual delegates in order to reach a wider audience. The conference will conclude with a panel discussion and a drinks reception to facilitate networking.

For further information please contact:

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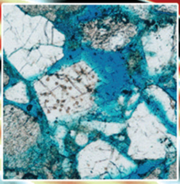

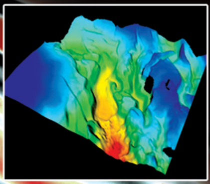

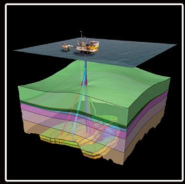

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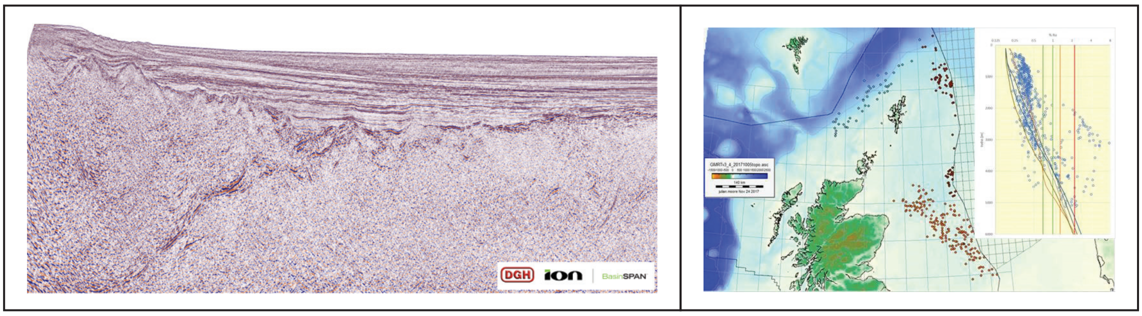
Interplay of heatflow, subsidence and continental break-up: a case study workshop

8-9 October 2018

The Geological Society, Burlington House, Piccadilly, London



In the past decade significant advances have been made in the understanding of the evolution of rifted margins. It has nonetheless proven difficult to match models of heatflow and subsidence during and after continental break-up with well data, seismic observations and field studies.

The aim of the meeting is to bring academia and industry together, particularly structural geologists and petroleum systems analysts with the aim of defining a common understanding of the data, models and challenges faced by the different disciplines interpreting and predicting structural evolution, heatflow and subsidence.

The workshop will take the form of keynote presentations followed by case studies in the following themes:

- Mechanisms of rifting and continental break-up
- Observations from borehole and high quality deep seismic data
- Challenges faced by petroleum systems analysts in applying models to real data.

The committee now invite submissions of case studies to supplement these themes and are particularly interested in examples where the current models do not adequately describe the observed data or examples where there are observed spatial and temporal variations in heat flow and subsidence along a continental margin. The case studies need to be data driven either seismic, wells or both. The workshop will also have dedicated break-out session where participants can discuss the issues outlined in the case studies, discuss potential solutions and then report back to the main meeting. We anticipate this workshop will be the impetus for cross-disciplinary research, follow-up workshops and a later conference.

The committee look forward to you joining us on the 8-9 October 2018 to participate in what promises to be an exciting and stimulating workshop.

Registration:

Registration open soon.

For further information and registration please contact:

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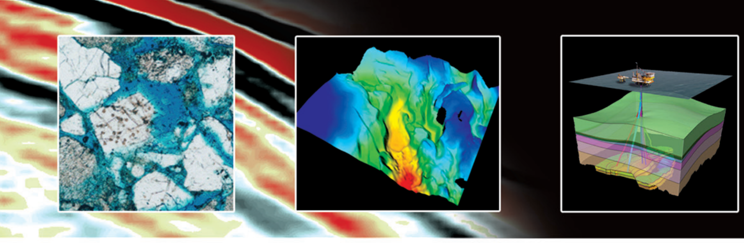

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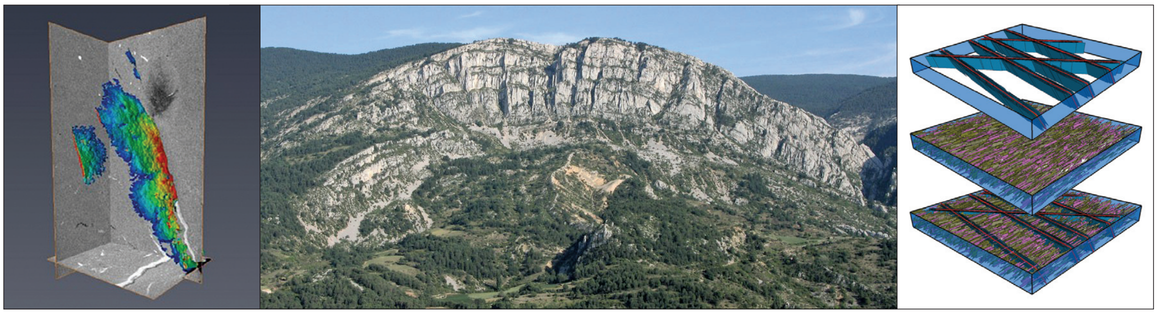
Call for Abstracts – Deadline: 31 May 2018

The Geology of Fractured Reservoirs

24-25 October 2018

The Geological Society, Burlington House, Piccadilly, London



A large proportion of the world's oil and gas is produced from fractured reservoirs, with new discoveries continuing to be made and put into development. This conference will explore the many ways in which the geology of fractures is fundamental to the understanding of fluid flow in the subsurface, and hence to predicting and monitoring reservoir performance.

Fractured reservoirs are those in which fractures have caused a significant increase in total permeability. Carbonate reservoirs, tight sandstone reservoirs, basement reservoirs and shale reservoirs are all commonly fractured, and present significant challenges to petroleum geologists. The focus of these challenges, but not their significance, changes throughout a field's life-cycle from exploration to production. Many geothermal reservoirs are also fractured, and share common challenges. This meeting will highlight how multidisciplinary work is essential to develop an applicable understanding of the behaviour of fractured reservoirs.

Themed sessions to include:

- Fracture properties at micro and well scale – detection and characterisation
- Fracture properties at reservoir to basin scale – from outcrops to seismic to regional models
- The flow behaviour of fracture systems – the interaction of fluids, rocks and stress
- The integration of data, disciplines and insights – advancing our knowledge of fractured reservoirs

Call for Abstracts:

Please submit paper and poster contributions to sarah.woodcock@geolsoc.org.uk by 31 May 2018.

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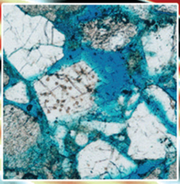

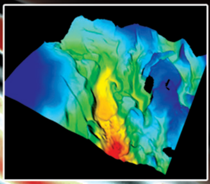

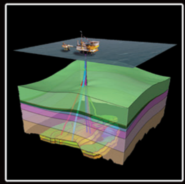

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Call for Abstracts – Deadline: 25 May 2018

Operations Geoscience Adding Value

7-8 November 2018

The Geological Society, Burlington House, Piccadilly, London

The main focus will be on the value operations geoscientists deliver and the pivotal role they play via the following topics:

- **The value of learning lessons well** – what is a lesson?; how are lessons learned and managed (e.g. avoiding non productive/invisible lost time)?; practical examples of lessons with demonstrable change; personal willingness to share failure/sub optimal performance
- **Risks and safety of operations** – identifying, managing, communicating risks and planning contingencies effectively
- **Formation pressure and geomechanics** – sharing good practice, techniques and knowledge, prediction and detection methods
- **The value of managing and interpreting data** – effective data management for field life, examples of cross company collaboration

Overarching themes:

- Value of these themes to **well life cycle**
- Sharing real world **examples and case studies**
- Importance of **personal behavioural skills** throughout (leadership, communication, relationship building and influencing others)
- Share good practice, showcasing **innovative approaches and technologies**

We look forward to active participation from our colleagues across subsurface, drilling and engineering disciplines to significantly broaden the main conference themes.

There will be a parallel poster session in the library.

Call for Abstracts:

Please submit paper contribution to sarah.woodcock@geolsoc.org.uk by 25 May 2018.

For further information and registration please contact:

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