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'Bottom-up' analysis identifies eastern Mediterranean prospects

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An existing TGS-Nopec regional 2D seismic survey over offshore the eastern Mediterranean and the recently acquired 2D lines over offshore Egypt reveal a mosaic of rift paleo-lows underpinning a thin Plio-Pleistocene section, a thick Messinian salt, a thin pre-salt Tertiary section, and a thick Mesozoic sag section.

Within the paleo-lows, large robust inversion structures (Syrian Arc folds) are apparent within drillable depths.

The Eastern Mediterranean basin is within the northeastern edge of the African plate where a Middle Jurassic-Recent, post-breakup stratigraphic section overlies a rifted terrain composed of a mosaic of various sized, localized Late Triassic-Early Jurassic rift subbasins. A recent interpretation shows continental to intermediate crust under the basin.

A generally east-west trending, north dipping, subduction-accretion complex (delineated by an east-west trending obduction zone) forms the boundary of the Eastern Mediterranean basin (EMB). A north-south trending major transform fault system composed of regional left-lateral strike-slip faults that separate the western African Plate from the eastern Arabian Plate constrain the basin in the east. The southern limits of inverted NE-SW trending Mesozoic depo-centers that extend through the Western Desert and Sinai Peninsula of onshore Egypt and through the northern portion of Israel's Negev Desert constrain the basin in the south. Lastly, the transition from continental and intermediate crust in the east to oceanic crust constrains the basin in the west.

Geologists have interpreted the EMB's present tectonic overprint to have developed during the following main tectonic events:

- Triassic-Early Jurassic transtensional rift
- Middle Jurassic-Early Cretaceous sag
- Late Cretaceous-Eocene Alpine transpressional inversion
- Latest Paleogene-to-Miocene internal plate adjustment
- Pliocene flooding.

Deep-seated regional fault trends fragment the present stratigraphic section overlying the basin. Two main regional fault trends, a NW-SE trend and a NE-SW trend are apparent. Subordinate fault trends developed oblique to the two main trends.

Geologists interpret these regional fault systems as paleo-faults, which they believe to be the key element to all Mesozoic and Cenozoic petroleum systems of the Eastern Mediterranean basin. The paleo-faults are responsible for:

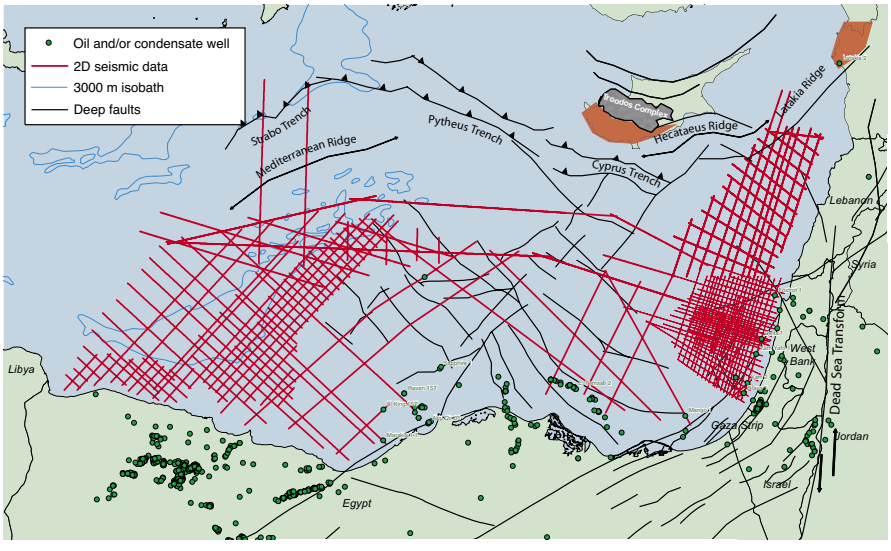
- Fragmentation of the basin into rift paleo-lows during the Triassic-Early Jurassic rift
- Inversion of the paleo-lows during the Late Cretaceous-Eocene Alpine inversion
- Periodic reactivation and disruption of post-inversion stratigraphic sections
- Distribution and/or redistribution of hydrocarbons from deep, mature, thermogenic source rocks vertically into the overlying pre-salt and post-salt sections following each reactivation
- Dislocations of the shelf margin along which zones of weaknesses developed and became entry points for delivery of coarse sediments to the basin.

Petroleum systems

Exploration offshore Egypt and Israel has demonstrated three proven working petroleum systems within the offshore EMB. Geologists base the three systems on trap, timing, and available reservoir. The three systems include:

- Petroleum System A: Jurassic carbonate reservoirs and Early Cretaceous turbidite sand reservoirs within Cretaceous inversion play (Syrian Arc)
- Petroleum System B: Oligocene-Miocene lowstand incised valley/submarine canyon play
- Petroleum System C: Basal and Mid Pliocene gas play

Recent exploration efforts within the offshore portion of the EMB resulted in close to 35 tcf of gas (approximately 2.5 tcf offshore Israel and Gaza Strip and the remainder offshore Nile delta) in Plio-Pleistocene reservoirs (Petroleum System C). The current industry paradigm insists that a biogenic source rock generated the enormous reserves of dry gas. Geologists base the biogenic gas interpretations on a biogenic source rock study. They concluded that biogenic source rocks produce methane gas with a recognizable carbon isotope signature (-60 to -66) and, by extension, biogenic processes generate all methane gases with similar carbon isotope signature trapped in shallow reservoirs. The success of exploration efforts within the Plio-Pleistocene section imposed a top-down ex-



TGS-Nopec acquired 16,000 km of non-exclusive 2D seismic data in the eastern Mediterranean Sea.

ploration bias onto the offshore portions of the EMB.

However, along the south and eastern rim of the EMB in the Western Desert, Egyptian Sinai, and southern Israel, onshore exploration targeted a different petroleum system. This system includes Middle Jurassic source rocks that reached thermal maturation in the Oligo-Miocene period and generated oil and gas, which migrated into Jurassic and Cretaceous carbonate and clastic reservoirs within Late Cretaceous-to-Eocene inversion structures (Syrian Arc folds). The large surface structures generated during the inversion period extends from northeast Syria through western Lebanon and Israel, south across the northern Sinai Peninsula, and through Egypt's Western Desert. The characteristics of the folds are remarkably consistent through the foldbelt.

Early exploration efforts offshore Sinai and Israel targeted similar large Late Cretaceous-Eocene inversion structures. Offshore Israel, the Yam-2 and Yam Yafo-1 wells tested 800 b/d of oil from Middle Jurassic carbonate reservoirs. Offshore Sinai, the Mango-1 well tested 10,000 b/d from Early Cretaceous turbidite sandstones.

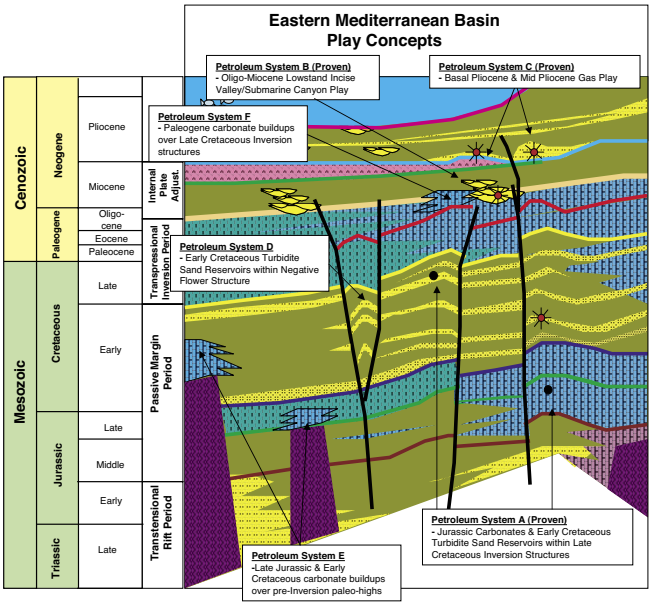
The earliest exploration efforts within the offshore Nile Delta targeted the offshore Messinian incised valley play extension of the onshore Abu Madi play. The traps in the Abu Madi trend are largely stratigraphic with porous fluvial sands infilling N-S trending Miocene incise valleys. Rich gas with a significant condensate component was discovered within this offshore extension of the trend. These gas-filled fluvial sands exhibit strong amplitude anomalies.

Soon after the discovery of the Abu Madi gas field, Phillips discovered the Abu Qir gas/condensate field in the western offshore Nile Delta. Late Miocene Abu Madi and Sidi Salim formation sand reservoirs trapped the gas/condensate in this field. The trap is a structural/stratigraphic trap and overlies portions of the NE-SW trending Qattara fault system (the west bounding fault system) to the Nile Delta sub-basin.

Egyptian geochemical analyses reveal that gas accumulations within the Abu Madi trend are from a thermally mature source rock with a mixed oil and gas kerogen and with no contribution from a biogenic source rock. A thermogenic source rock at a post-mature maturation stage generated the gas/condensate in the Abu Qir field.

A thermally mature Mesozoic source rock generated these hydrocarbon accumulations, and that inference imposed an early bottom-up exploration paradigm (deep thermally mature Mesozoic source rock generating hydrocarbons that migrated into younger traps and reservoirs).

In support of that approach, geologists have commonly encountered early-paradigm gas shows within Cretaceous sands in deep offshore Israel wells that test the large Late Cretaceous-Eocene inversion structures. Feinstein et al. (AAPG International Conference, 1993) commented that in the Yam-1 and Yam-2 wells the gas composition in the Cretaceous sands varied with depth from shallower dry gas to deeper gas with condensate. The investigators believed that



The area's tecono-stratigraphic evolution reveals several play concepts.

the stable carbon and hydrogen isotope data further suggested an admixture with variable amounts of biogenic gas, mainly methane.

The conclusion was: "Despite the differences indicated, all gas shows (including the dry gas) are oil associated and thermally derived at maturity levels between 0.7-0.9% ratio of organic content equivalents." Evidence implies that the gas shows are all oil-associated and from a common oil source but at different expulsion times.

Recently, gas associated with significant amounts of condensate within Pliocene reservoirs (Sapphire-1 well in the western offshore Nile Delta tested 35 MMcf/d and 1,100 b/d of condensate) has demonstrated that a Pre-Messinian thermally mature source rock is generating thermogenic hydrocarbons.

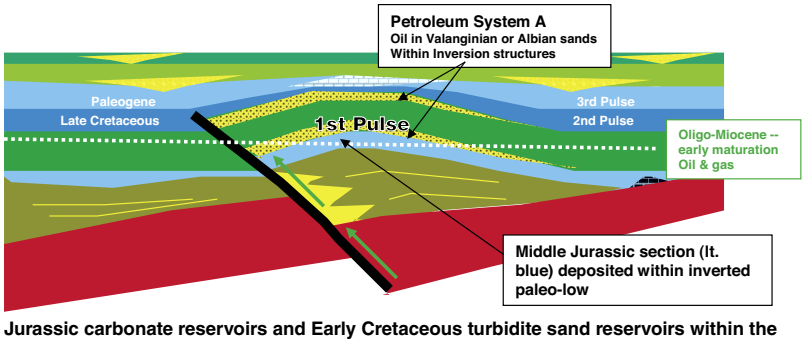
In addition to the increased association of gas with condensate in Plio-Pleistocene reservoirs, geologists recognized that a close association of Plio-Pleistocene fields exists with the deep-seated paleo-faults over the offshore Nile Delta area. Western Plio-Pleistocene gas and gas/condensate fields are over or proximal to the main NE-SW trending Qattara fault system, while eastern Plio-Pleistocene gas and gas/condensate fields are over or proximal to the main NW-SE trending Misfaq-Bardawil fault system.

In recent discovery, BP Egypt tested 37.4 MMcf/d and 741 b/d of condensate from Early Miocene sands in the Raven-1 well. The deposition of slope channel sands uplifted during reactivation along the NW-SE trending Qattara fault system formed the structural/stratigraphic trap.

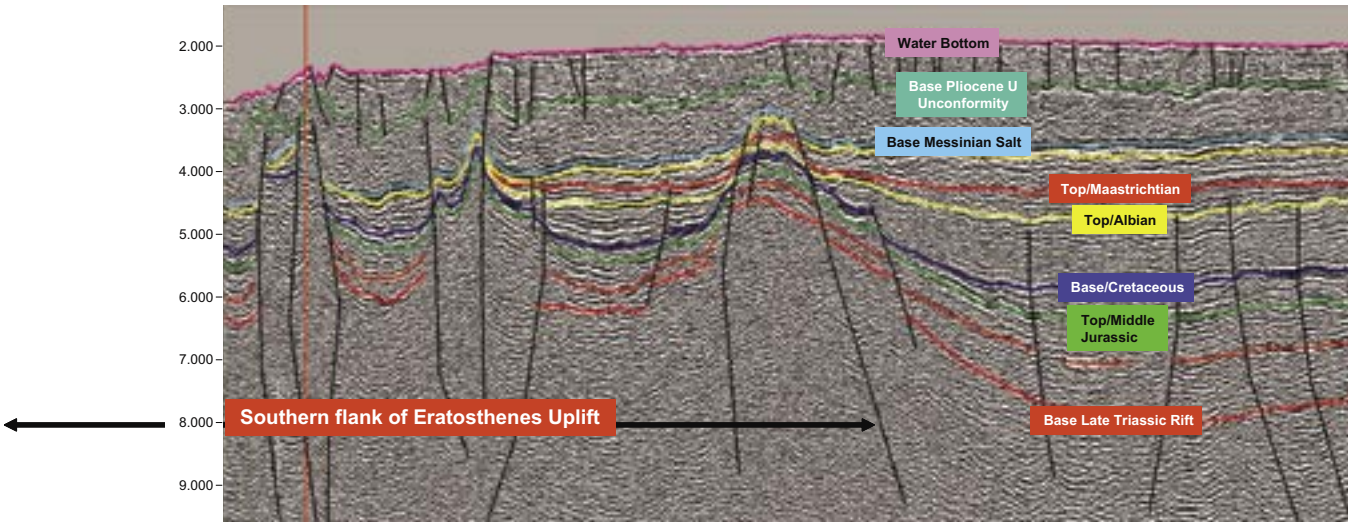
Similar to the Nile delta Plio-Pleistocene gas discoveries, geologists associate the Israeli and Gaza Strip Basal Pliocene discoveries with deep-seated paleo-faults.

Indeed, an explorationist could observe that within the offshore portion of the EMB, there is a progressive change in hydrocarbon type with depth from oil within the Mesozoic section to rich gas/condensate with Oligo-Miocene reservoirs, to predominately methane gas trapped within Pliocene reservoirs. Geologists associate the preponderance of the accumulations with deep-seated paleo-faults.

The working exploration paradigm may need to be examined again to understand the petroleum systems in the offshore areas of the Eastern Mediterranean basin.



Jurassic carbonate reservoirs and Early Cretaceous turbidite sand reservoirs within the Cretaceous inversion play trapped hydrocarbons that migrated from thermally mature Mesozoic source rocks.



Seismic data in the Eastern Mediterranean basin and 2D lines offshore Egypt reveal a mosaic of rift paleo-lows underpinning a thin Plio-Pleistocene section, a thick Messinian salt, a thin pre-salt Tertiary section, and a thick Mesozoic sag section.

The tectonic evolution analyses envision episodic pulses of transpressional wrench movement during the Late Cretaceous-to-Eocene inversion period, the Late Paleogene adjustment period, and the Pliocene flooding period. Each younger period of reactivation would "punch upward" through the stratigraphic section and suddenly open vertical migration pathways into progressively younger reservoirs. Robust and organic-rich Mesozoic source rock deposited within or over the rift sub-basins reached progressively more advanced stages of maturation between each reactivation pulse.

Using the Feinstein et al model, gas shows illustrate a progressive increase in the proportion of heavier fractions associated with the gas with an increase in the depth of a gas show. All are oil-associated and are from a common oil source, but at different expulsion times.

Here is an interpreted tectonic evolution/source rock deposition/maturation/migration scenario:

- Paleo-lows formed during transtensional wrench movement along paleo-fault trends
- Organic-rich Triassic-Early Jurassic rift and Middle Jurassic-Early Cretaceous passive margin sediments deposited selectively within and above the paleo-lows
- Applied transpressional deformation inverted paleo-lows during the Late Cretaceous-Eocene
- Sediment overburden reached critical thickness over inverted paleo-lows, while organic rich Mesozoic source rocks reached maturity during the Oligo-Miocene. Organic rich Mesozoic source rocks within proximal paleo-lows generated liquid hydrocarbons, and the hydrocarbons moved via fault systems into Jurassic and Early Cretaceous reservoirs
- Wrench reactivation along paleo-fault systems occurred during the Late Miocene. Late, mature, organic-rich Mesozoic source rocks generated later phase hydrocarbons. Re-migrated hydrocarbons moved vertically through Early Cretaceous, Late Cretaceous, Paleogene, and Early Neogene sections. During vertical movement, hydrocarbons were progressively fractionated into lighter hydrocarbons
- Deposition continued northward and westward into the more distal portions of the basin and matured organic rich Mesozoic source rocks within distal inverted paleo-lows. Organic-rich Mesozoic source rocks within proximal paleo-lows became over-mature and entered the gas phase
- Wrench reactivation along paleo-fault systems occurred during the Early Pliocene. Over mature organic rich Mesozoic source rocks generated gas. Re-migrated oil/condensate hydrocarbons moved vertical through Early Cretaceous, Late Cretaceous Paleogene, and Neogene section. During vertical movement, hydrocarbons were progressively fractionated into lighter hydrocarbons until methane gas with some condensate entered Pliocene reservoirs
- Continued migration of gas into Pliocene reservoirs displaced condensate within Pliocene reservoirs.

This bottom-up approach offers a more optimistic way of examining the interpreted tectonic evolution/source rock deposition/maturation/migration scenario of the EMB and opens more exploration opportunities. If a progressively maturing deep Mesozoic source rock generated the enormous quantities of hydrocarbons found within Tertiary reservoirs, potential reservoirs within structural or stratigraphic traps along the vertical migration pathways should also be charged.

Independent of the regional study, L&W Geosciences constructed burial histories based on the interpreted horizons by along TGS-Nopec eastern Mediterranean east-west trending dip lines offshore Lebanon. L&W concluded that the Triassic section is consistently overmature, the Jurassic section is middle-to-high maturity, and the Middle Cretaceous section is early- to mid-maturity, which supports the bottom-up exploration approach.

TGS-Nopec Geophysical Co. acquired 16,000 km of non-exclusive 2D seismic data in the eastern Mediterranean Sea. During the survey, the company also acquired gravity and magnetic data that provided structural constraint during data interpretation.

The company acquired and processed the regional 2D seismic data to image deeply into the Pre-Messinian Salt stratigraphic section. Coupled with the acquired gravity and magnetic data the seismic data provides structural information and constraints on the underlying Tertiary and Mesozoic stratigraphic sections.

Deep Seek Exploration Experts LLC interpreted the survey with support of the gravity data, magnetic data, and regional knowledge. During the investigation, the company mapped 10 horizons from water bottom to top/rift breakup. It also identified prospects and lead areas for the proven petroleum systems. Prospects and leads are large with individual maximum potential reserves between 1-3 Bbbl.