Hydrocarbon plays and prospectivity of the SE Mediterranean

Avraam Zelilidis, Professor
Department of Geology, University of Patras
Red symbols show the areas with mud volcanoes on the Mediterranean Ridge: A. Cobblestone area 3 (Prometheus), B. Pan di Zucchero, C. Prometheus 2, D. Olimpi.

I.A.P.=Ionian Abyssal Plain; S.A.P.=Sirte Abyssal Plain; H.A.P.=Herodotus Abyssal Plain (modified from Ten Veen et al., 2004).
Southern part: Mediterranean Ridge (modified from Chamot-Rooke et al., 2005), separated into three distinct areas.

**AREA A:** Example from seismic line between Cephalonia and Zakynthos Islands (modified from Kokkinou et al., 2005). The red arrows show the possible hydrocarbon fields.

1,2: Pliocene and Miocene clastics. 3: Mesozoic carbonates, 4: Triassic evaporites.
Maravelis et. al., 2012
Γνωρίζουμε ότι:
Α. Το μήκος της ράχης φθάνει τα 1500km.
Β. Το πλάτος της ράχης κυμαίνεται από 150 - 320km.
Γ. Οι κλίσεις της ράχης είναι πιο ήπιες στο νότιο τμήμα της 1-2μοίρες.
Δ. Η μορφολογία της ράχης επηρεάζεται από την σημερινή τεκτονική.
Ε. Ο χρόνος δημιουργίας της είναι μέσο Μειόκαινο, έγινε σχεδόν μαζί με το Ελληνικό τόξο, και πριν τη δημιουργία των Μεσσήνιων εβαποριτών.
Γνωρίζουμε ότι:

ΣΤ. Υπάρχουν λεκάνες πίσω από τη ράχη με μεγάλο πάχος κλαστικών αποθέσεων

Ζ. Το πάχος της ιζηματογενούς ακολουθίας της ράχης είναι μεγάλο, ξεπερνώντας κατά θέσεις τα 10-12km

Η. Στην ιζηματογενή ακολουθία αναγνωρίστηκε η ύπαρξη των Μεσσήνιων εβαποριτών που το πάχος τους κυμαίνεται από 0 μέχρι και 2km
Η κατανομή των Μεσοχόνιων εβαποριτών: SCALERA, 2006
Υπάρχουν Μεσσήνιοι εβαπορίτες με μικρό πάχος πάνω στη ράχη και με μεγάλο πάχος στο backstop.
Γνωρίζουμε ότι:

Θ. Σε τρεις περιοχές αναγνωρίστηκαν, μελετήθηκαν και αξιολογήθηκαν ηφαίστεια λάσπης που δημιουργούνται εξαιτίας διαφυγής υδρογονανθράκων.

Akhmanov & Woodside, 1998
Γνωρίζουμε ότι:

I. Το μέσο βάθος του νερού είναι 2.1km (από 1.2-3.0 km)

Κ. Υπάρχουν πολλές τάφροι πίσω από τη ράχη – περιοχή που αναφέρεται ως backstop (Matapan, Poseidon, Strabo) - με ηλικία Μέσο Μειόκαινο, βάθος 2.5-3.0 km, και πάχος ιζηματογενούς ακολουθίας μετά τη δημιουργία των λεκανών, 6.5km.

Λ. Υπάρχουν λεκάνες μπροστά από τη ράχη – abyssal plains (Messina, Sirte, Herodotus)- με βάθη από 3.0-4.2 km.
Μορφο-βαθυμετρικός χάρτης της Μεσογείου, από MediMap Group, Loubrieu B. & J. Mascle (τροποποιημένος από Huguen et al., 2006).
Mediterranean Ridge in Eastern Mediterranean: AREA B is the one with the seven backstop basins – trenches (Maravelis et al., 2011).


Detailed block diagrams from Southern Crete, with mud volcanoes from Olympus field on Mediterranean Ridge, Gavdos, Ptolemeus, Pliny and Stravon basins behind the ridge (modified from Huguen et al., 2006).
Messara Basin is a restricted basin formed in the northern margins of the Cretan Trench, whereas Gavdos Island is the southern margin of this Trench.

Messara Basin sediments, up to 2km thick, mostly Tortonian in age, consist of fine grained sediments, rich in organic carbon, could be the sources for the possible hydrocarbon field of Cretan Trench.

Within the Messara basin a biogenic gas field was developed
AREA B: An example from the six backstop basins southward to Crete Island (Gavdos, Gortys, Poseidon, Ptolemeus, Pliny and Stravon Trenches) where seismic lines show basin geometry and sedimentary configuration with the presence of Messinian evaporites (Maravelis et al., 2012).
Structures that affect AREA B. Anticlines and Plio-Quaternary depocenters, both onshore and offshore, represent possible hydrocarbon plays (Maravelis et al., 2011).
AREA C: 1 KASTELORIZO - HYDRATES

5 trillion cubic meters of methane after hydrate degradation

Block diagram showing five areas with mud volcanoes (Amsterdam, Kazan, Kula, Athina, Thessaloniki) (from Lykousis et al., 2009).

Bathymetric map with major morphological features of Anaximandros high and peripheral basins (from Lykousis et al., 2009).
Levantine Basin: Cyprus is in co-operation with Israel
1.7 million barrels of oil and 3.5 trillion cubic meters of gases
Herodotus Basin – related to Nile delta
Κύπρος

Figure 5 (continued): (b) NW-NE seismic line over the central part of the Levantine Basin (offshore Lebanon). The western portion of the line covers the eastern margin of the Erethosthenes Seamount, where the Cretaceous is seen to overlap onto its structure (see inset). Section width approximately 180 km.
1. Κυμαίνομενο πάχος Μεσσήνιων εβαποριτών
2. Έντονη παραμόρφωση των υποκειμένων
3. Μεγάλο πάχος της Μετα-μειοκαινικής Ακολουθίας
Herodotus basin where OMV work on its southwestern part.
Maps according Krois et al., 2010 and Gabor Tari et al., 2010
Note difficulty of onshore/offshore stratigraphic correlation due to lack of offshore wells.
Bathymetrical map which shows the two basins. NE of Cyprus is the Levantine basin and NW of Cyprus the Herodotus abyssal plain. (Geomap).

.2: Stratigraphic cross section of the Herodotus basin and Eratosthenes continental block (Montadert & Nicolaides, 2010).
Bathymetric map that shows the four turbidity sources in the Herodotus basin (Reeder et al., 2000).
<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>LEVANTINE BASIN</th>
<th>HERODOTUS BASIN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AGE OF SEPARATION</strong></td>
<td>CRETACEOUS</td>
<td>CRETACEOUS</td>
</tr>
<tr>
<td><strong>AGE OF DEVELOPMENT</strong></td>
<td>MIDDLE MIOCENE</td>
<td>MIDDLE MIOCENE</td>
</tr>
<tr>
<td><strong>LENGTH</strong></td>
<td>~325 KM AVERAGE</td>
<td>~450 KM AVERAGE</td>
</tr>
<tr>
<td><strong>WIDTH</strong></td>
<td>~155 KM AVERAGE</td>
<td>~255 KM AVERAGE</td>
</tr>
<tr>
<td><strong>WATER DEPTH</strong></td>
<td>&gt;2 KM</td>
<td>&gt;3 KM</td>
</tr>
<tr>
<td><strong>EXTEND</strong></td>
<td>~50.375 KM²</td>
<td>~113.000 KM²</td>
</tr>
<tr>
<td><strong>SEDIMENT THICKNES</strong></td>
<td>10-14 KM</td>
<td>12-15 KM</td>
</tr>
<tr>
<td><strong>SOURCE ROCKS</strong></td>
<td>Pliocene clays, Cretaceous clays, Jurassic carbonates and marls, Triassic clays and siltstones</td>
<td>Plio-Pleistocene siltstones and sapropels, Miocene sapropels and calcareous siltstones, U. Jurassic-L. Cretaceous fine sediments</td>
</tr>
<tr>
<td><strong>POTENTIAL RESERVOIRS</strong></td>
<td>Plio-Pleistocene, Messinian, sandstones, Cretaceous sandstones, limestones and carbonate reefs, Jurassic sandstones, limestones, dolomites and oolitic limestones, Triassic sandstones</td>
<td>Plio_Pleistocene turbidite sands and sand formations rich in carbonate material Miocene biomicrites, bioarenites, fossiliferous micrites and calcarenites, porous sediments of Jurassic and Cretaceous</td>
</tr>
<tr>
<td><strong>SEAL ROCKS</strong></td>
<td>Messinian evaporites, Triassic, Jurassic and Cretaceous clays and marls, Triassic and Jurassic evaporites</td>
<td>Messinian evaporites, calcareous siltstones lower-middle Miocene and siltstones of Pleistocene</td>
</tr>
<tr>
<td><strong>TRAPS</strong></td>
<td>Structural and stratigraphic (anticlines, pinch-outs, unconformities)</td>
<td>Structural and stratigraphic (anticlines, pinch-outs, unconformities)</td>
</tr>
<tr>
<td><strong>MIGRATION</strong></td>
<td>Faults</td>
<td>Faults</td>
</tr>
<tr>
<td><strong>OIL (BBL)</strong></td>
<td>1.68</td>
<td>≥1.68</td>
</tr>
<tr>
<td><strong>NATURAL GAS (TCF)</strong></td>
<td>122</td>
<td>≥122</td>
</tr>
</tbody>
</table>

*Elia et al., 2013*
Potential source, reservoir and seal rocks

Several fine-grained sedimentary rocks may serve as potential source rocks, such as Carboniferous mudstones, Permian shallow carbonates, Early Cretaceous argillites, Early Cretaceous (Late Aptian) calcareous mudstones, Paleocene siltstone enriched in organic dentritus, Miocene (Burdigalian-Langhian) calcareous mudstones, Late Miocene (Tortonian) sapropels, Pio-Pleistocene sapropels and mudstones.

Potential reservoir rocks such as: Late Carboniferous mud-supported conglomerates and limestones, Late Permian-Triassic dolomites and limestones, Late Cretaceous (Turonian) limestones, Late Cretaceous limestones, Eocene (Ypresian-Bartonian) arenite cemented by poikilitic calcite, Late Eocene-Early Oligocene (Priabonian-Rupelian) subquartzose arenites, Early Miocene (Aquitanian) Calclithites, Miocene (Serravallian) fossiliferous micrites, Late Miocene (Tortonian/Messinian) detrital biomicrites, Late Miocene (Tortonian/Messinian) biocalcarenites, Pio-Pleistocene carbonate-rich open marine and turbidite sands exist.

Impermeable sedimentary rocks that could provide top and/or lateral seals can be found in the: Early Cretaceous argillites, Early Cretaceous (Late Aptian) calcareous mudstones, Miocene (Burdigalian-Langhian) calcareous mudstones, Messinian evaporites and Pio-Pleistocene mudstones.
Potential Trap Style

Several trap styles may be present within the potential M.R. petroleum province including both structural and stratigraphic traps.

Structural traps may include traps formed by both diapiric and compressive tectonic processes. Diapiric processes lead to upward movement of both salt and mud and can create anticlinal structures that could form petroleum traps. Compressive tectonic processes commonly lead to the development of large-scale contractional folds and thrusts. Such contractions are common in convergent plate boundaries (e.g. M.R.) leading to the development of major trap anticlines. Stratigraphic traps are mainly attributed to the occurrence of Messinian evaporites within the M.R. These rocks overly, either unconformable or directly, typical basinal, hemipelagic, pelagic, and turbiditic sediments and can lead to the creation of truly massive traps.
Seven potential hydrocarbon plays have been distinguished within the Greek Mediterranean region including:

1) Post-salt (Pliocene to recent) sands: These rocks that consist the coarser portion of the Plio-Pleistocene sedimentary succession can potentially act as reservoir rocks. As potential source rocks may serve the deeper, older sediments in places where Messinian salt is absent (northeast edge of the M.R.), or the surrounding sapropels and mudstones (South Cretan Margin),

2) Large-scale anticlines and faulted anticlines, Paleozoic to Pliocene in age, common in the narrow and very close to the H.T.S. northeast edge of the M.R. that may act as major petroleum traps.

3) Fault blocks and combined fault/stratigraphic traps, Mesozoic to Pliocene in age: Well presented traps of that type are abundant in the northeast edge of the M.R. (Figures 7 and 8) and in the South Cretan Margin.

4) Sub-salt (pre-Messinian) plays: Establishment of sub-salt sediments with source rock and/or reservoir potential is fundamental since evaporites may potentially serve as a first class seal immediately below the base of the salt. Likewise, determination of thickness and distribution of the Miocene evaporites are also essential. Possible plays of this type are abundant in the M.R. and include: (A) the northwest edge of the M.R., (B) offshore Greece, south of Crete and (C) M.R. foreland.
(5) mud diapirism that may serve as direct petroleum indicator in this poorly understood basin and possible traps through anticlinal structures that can be formed (e.g. Olimpi and Prometheus 2).

(6) diapiric processes stimulate the upward movement of salt forming anticlinal structures that may act as petroleum traps (e.g. between the Pliny and Strabo Trenches).

(7) M.R. foreland exhibits strong lateral variations in sedimentary fill and thickness, as well as in crustal origin and thus, the distinguished potential plays that are derived by regional oil-geological considerations and regional seismic lines may be evaluated. Given the Miocene evaporites distribution (absent westwards, towards the Libyan margin) and thickness (increase eastwards), and the Plio-Quaternary sedimentary and Cretaceous oceanic crust thickness (increase eastwards); the eastern parts of the M.R. (Herodotus abyssal plain) are considered the most prominent regions relative to the western parts (Sirte abyssal plain, Libyan margin).
RESULTS
Thank you for your attention