

# **Syn-Tectonic Sedimentation Over a Miocene Gas-Bearing Structure – Sequence Stratigraphy Case Study of the Aphrodite Field, Levant Basin\***

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## **Abstract**

The Aphrodite gas field located in the western Levant basin is a large four-way dip closure segmented by a series of NW trending layer-bound faults. The reservoir is comprised of stacked deep marine turbidite sandstones with interbedded mudstones and siltstones of Oligocene - Miocene age, sealed by Late Miocene, Tortonian marls and in turn by the Messinian salt. Sequence stratigraphic analysis was used to constrain timing of structural development and provides a consistent basis for correlation of the reservoir interval. The field was discovered in 2011 by Noble's Cyprus A-1 well. An appraisal well, Aphrodite-2 drilled by the Pelagic Group discovered gas on the eastern flank of this structure in 2012, and in 2013 a further appraisal well, Cyprus - A2a was drilled by Noble to evaluate the northern part of the structure. All three wells proved columns of dry gas in Early Miocene (Aquitania) - Late Oligocene (Chattian) sandstones equivalent to the "Tamar Sands". Prior to the drilling, the field was covered by few 2D data and by 3D surveys of various vintages. A well -log sequence stratigraphic analysis of well Aphrodite -2 (RPS 2014) constrains the timing of structural development observed from 3D seismic data. The deep water setting during the Oligocene and Miocene makes such study challenging in contrast to study of coastal onlaps in shallow water environments. A biostratigraphic framework based on occurrence of diagnostic species together with the patterns of abundances and diversity of micro and nannofossils was integrated with wireline log data and lithofacies. Peaks in nano- and microfossil abundance were used as indicators of condensed sedimentation which when integrated with lithofacies and wireline information enabled discrimination and dating of maximum flooding events and sedimentary processes such as gravity flow deposition. Changes in microfossil assemblage and abundance minima were associated with sequence boundaries. Each depositional

sequence defined in this way was calibrated to published zonation schemes and to the sea level curve of Haq et al 1987. The seismic data indicate that the structure began to develop during the Early Miocene (Burdigalian) and that deformation continued to the Middle Miocene (Tortonian). The structure is not recognized at the base of the Messinian salt layer. Onset of structural development coincided with cessation of sand deposition at Aphrodite suggesting an overriding tectonic control on sand distribution within the Levant basin. It was also found that few, low confidence biostratigraphic events could be identified in the Middle Miocene owing to extensive reworking and this may also reflect active tectonism. The development of the Aphrodite structure appears to be simultaneous with the other gas-bearing structures in the Levant Basin. Its exact timing as revealed in the Aphrodite-2 well can be used as a benchmark for a basin-wide study if and when information from more wells is released in the future. Using Pelagic's 3D data we observed that structural development at the western flank of Leviathan closely matches Aphrodite. The mechanism that formed these contemporaneous "Syrian Arc II" structures is interpreted in the majority of studies as oblique compression induced by the on-going plate collision between the Africa and Eurasia plates along the Cyprus Arc and the Latakia Ridge but the reasons for deformation being mainly confined to the Middle Miocene remain unclear.

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## Geosciences Technology Workshops 2019

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Miocene Gas-Bearing Structure -  
Sequence Stratigraphy Case Study of  
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**ISHAIGROUP**

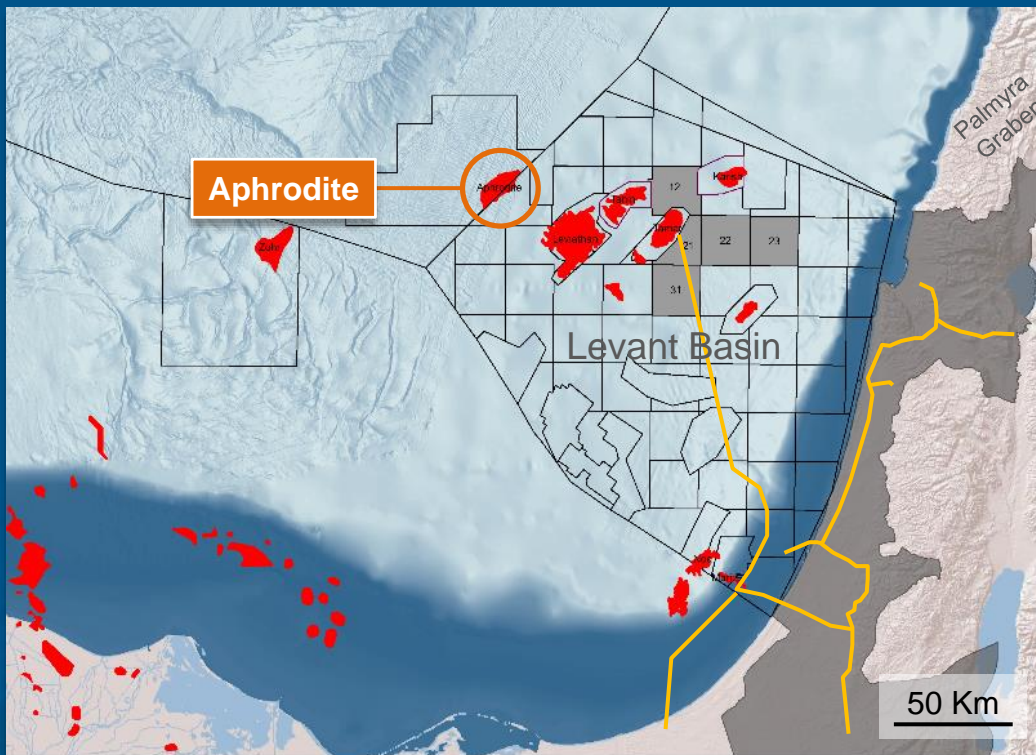
Pelagic

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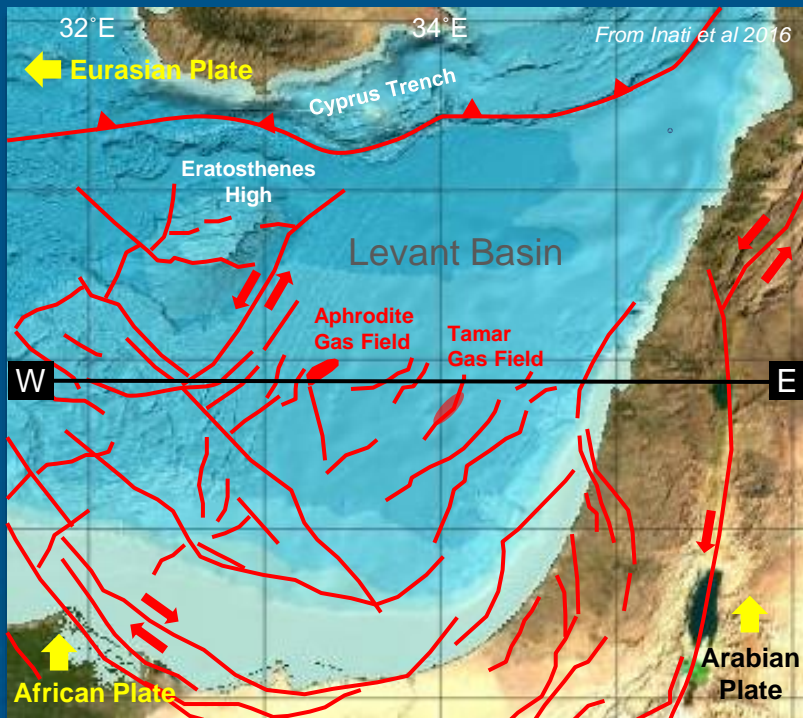
*26-27 February 2019 · Tel Aviv, Israel*

# Levant Basin Gas Fields

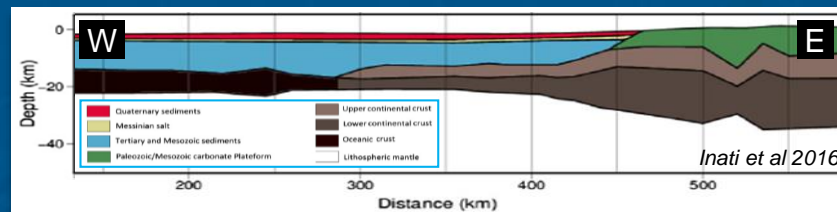
- Aphrodite was discovered by Noble in 2011.
- Two wells have been drilled within Block 12 Cyprus and one well Aphrodite - 2 within the Ishai Block Israel.
- All three wells encountered gas – bearing reservoir sands.
- The Aphrodite field is a straddling accumulation of dry gas.



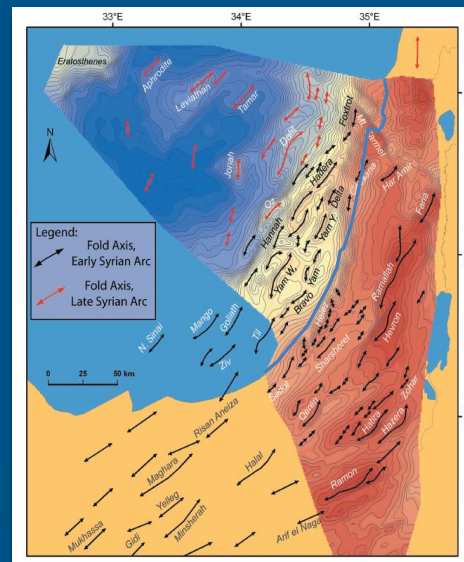
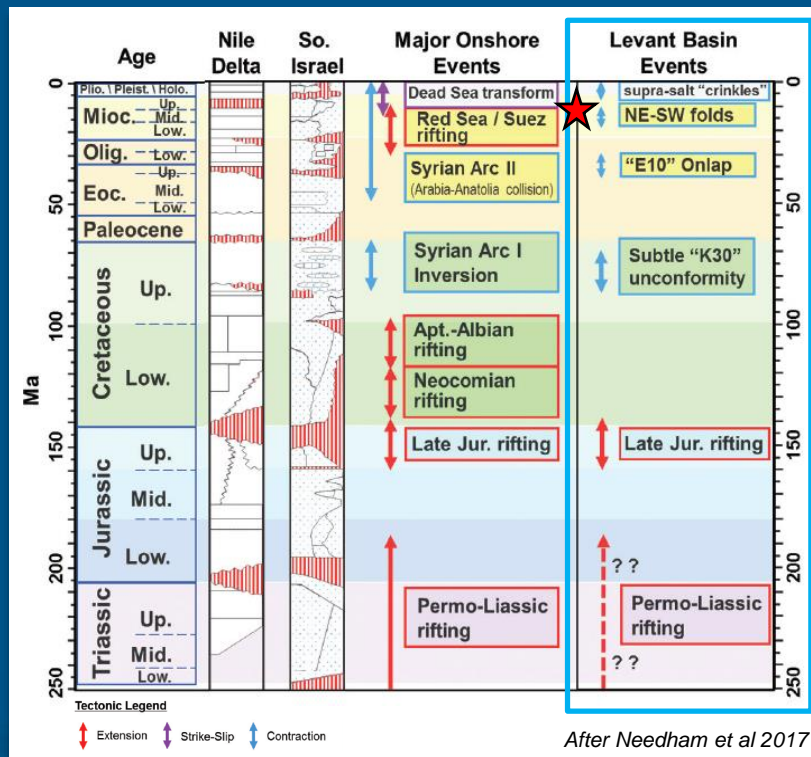
# Regional Structure – Levant Basin



- In the Levant basin, a thick pile of Mesozoic – Recent sediment overlies thinned continental crust.
- Interaction between the African, Arabian and Eurasian Plates has resulted in a series of large compressional structures – specifically the “Syrian Arc-II” anticlines.
- Very large volumes of biogenic gas have been discovered in Oligo-Miocene sandstones within simple 4-way dip closures segmented by NW-SE faults.
- The Aphrodite structure is similar to Tamar and has a closure of approximately 145Km<sup>2</sup>.



# Tectonic Events & Gas – Bearing Structures



- Cretaceous -Syrian Arc I identified within the Israeli nearshore “platform”.
- Tertiary – Syrian Arc II identified only within the deepwater area offshore Israel.
- NW-SE faults segment Syrian Arc II structure, also observed offshore Lebanon.

# Regional Profile

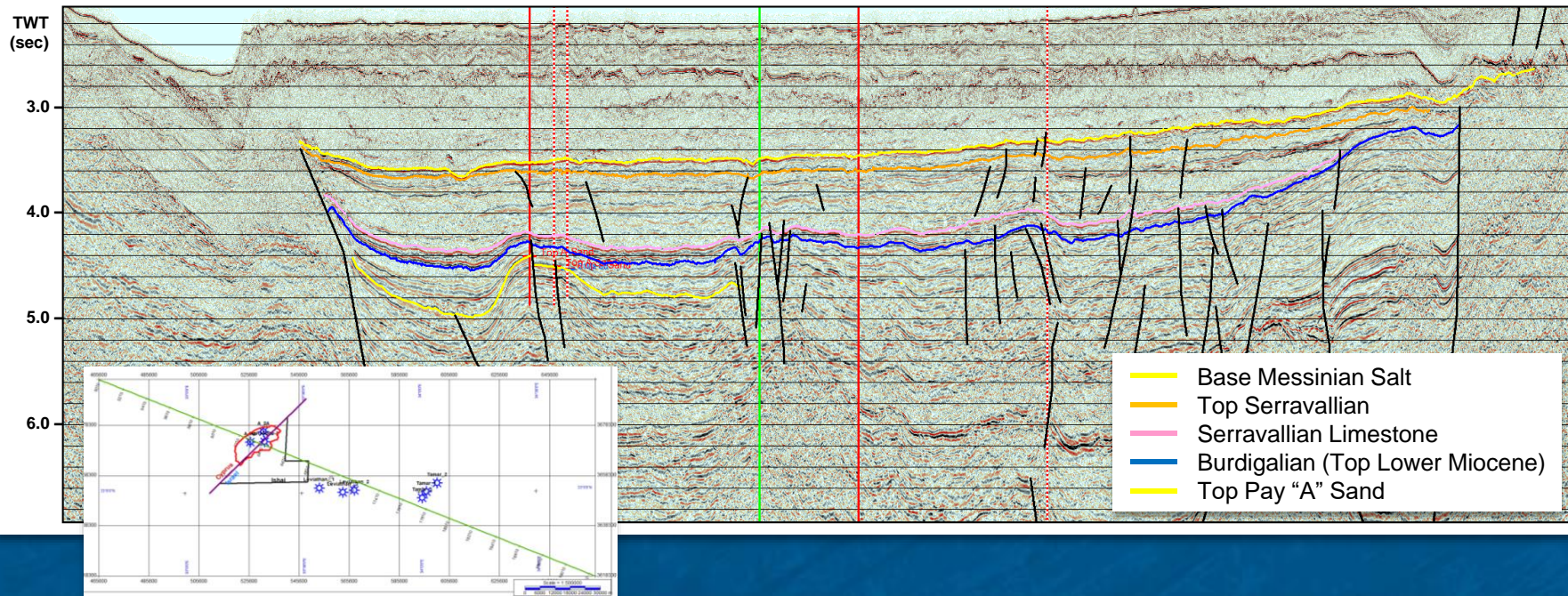
Eratosthenes High

Aphrodite

Leviathan

Tamar

Israeli Platform

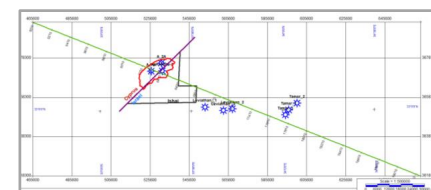
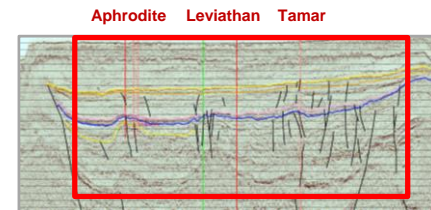
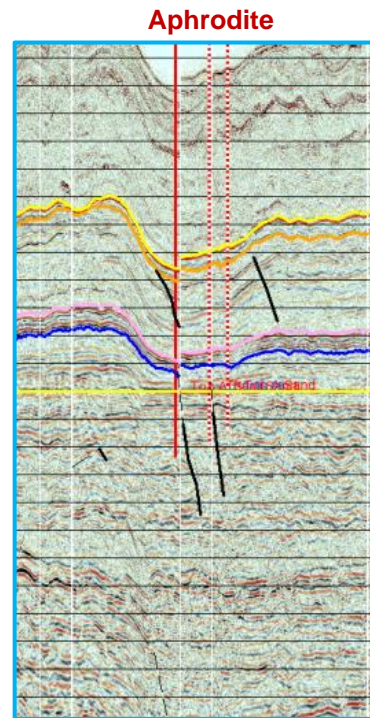
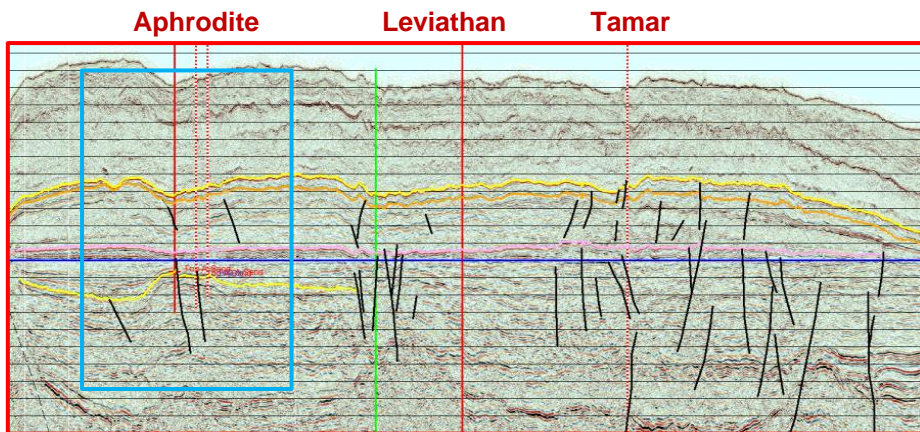


# Regional Profile (2D) Flattened

This regional 2D profile is not in true dip direction but flattening shows:

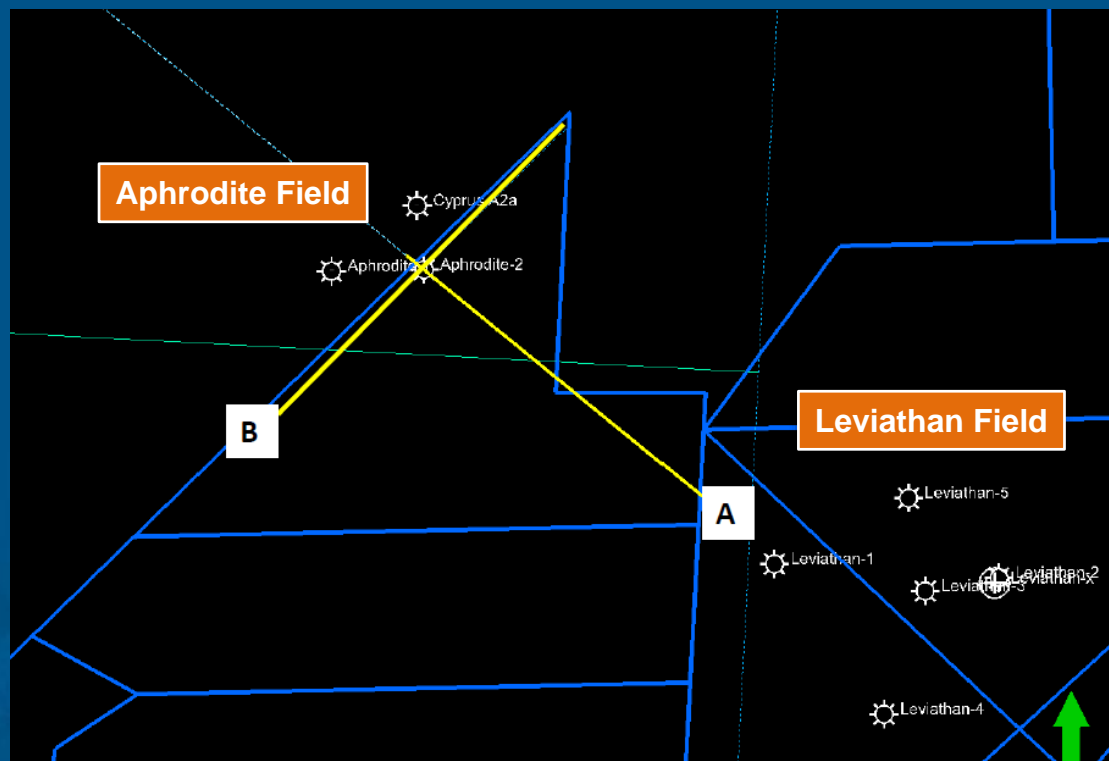
- Structural timing at Aphrodite is the same at Leviathan and Tamar
- The Blue to Pink (Burdigalian – Serravallian Limestone) is regionally consistent (tectonically passive)
- Isopach variation between “Top A” – Yellow (intra -Aquitanian) and Burdigalian - Blue
- Consistent interval beneath “Top A” (objective reservoir interval)

This can be examined in greater detail using higher resolution 3D data from Aphrodite; shown in the following slides

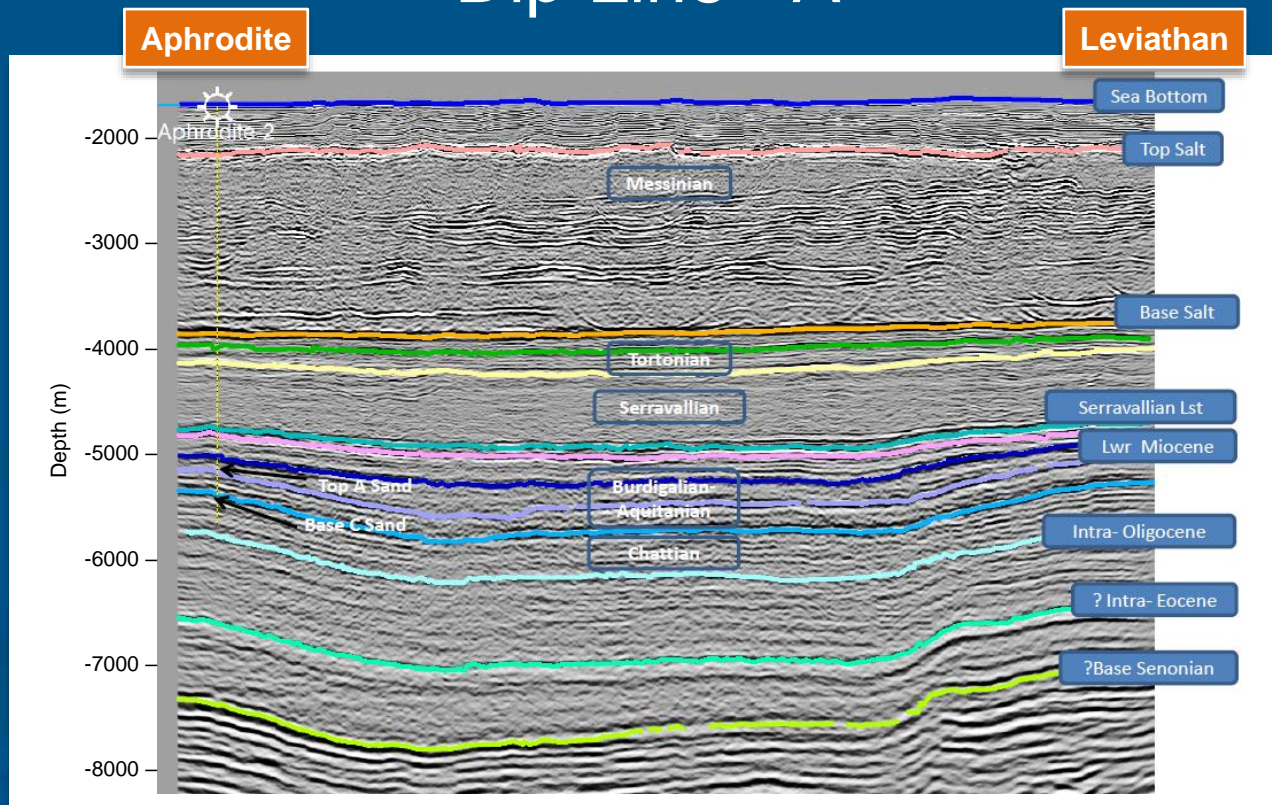


- Base Messinian Salt
- Top Serravallian
- Serravallian Limestone
- Burdigalian (Top Lower Miocene)
- Top Pay "A" Sand

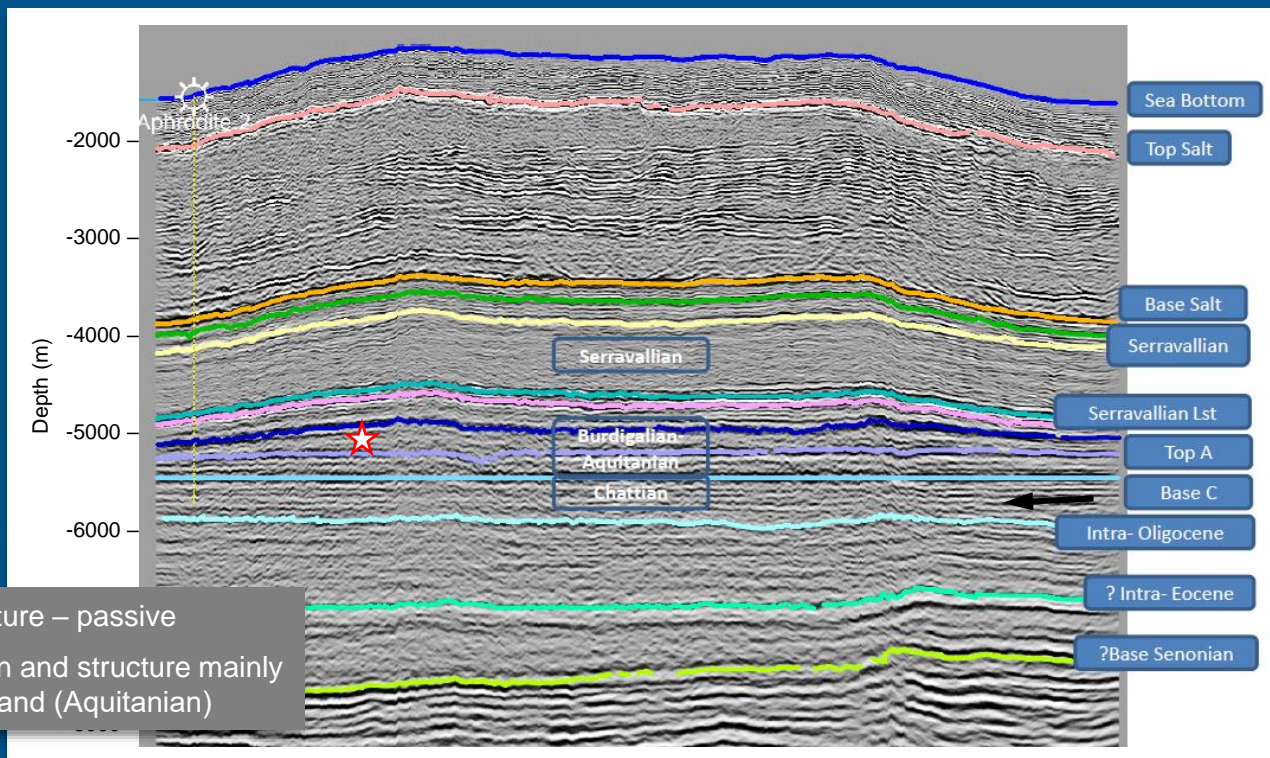
# Ishai - 3D Data



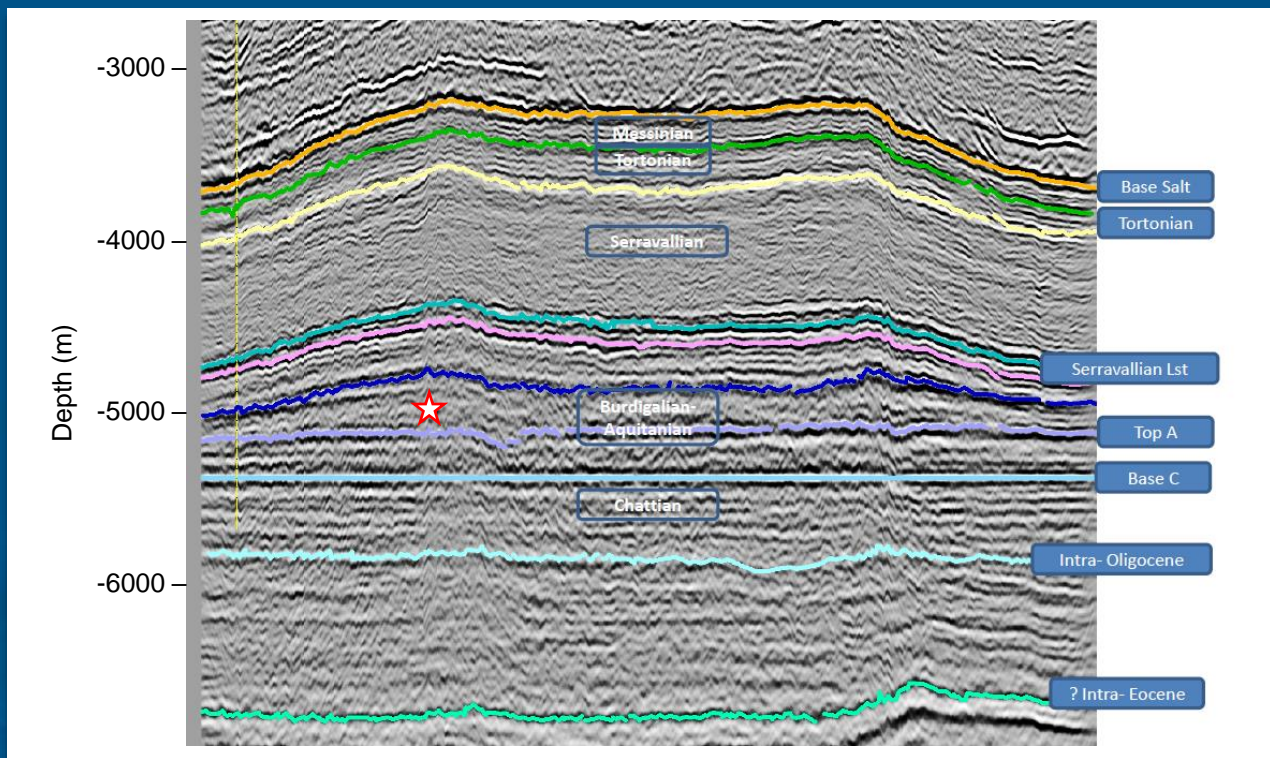
# Dip Line - A



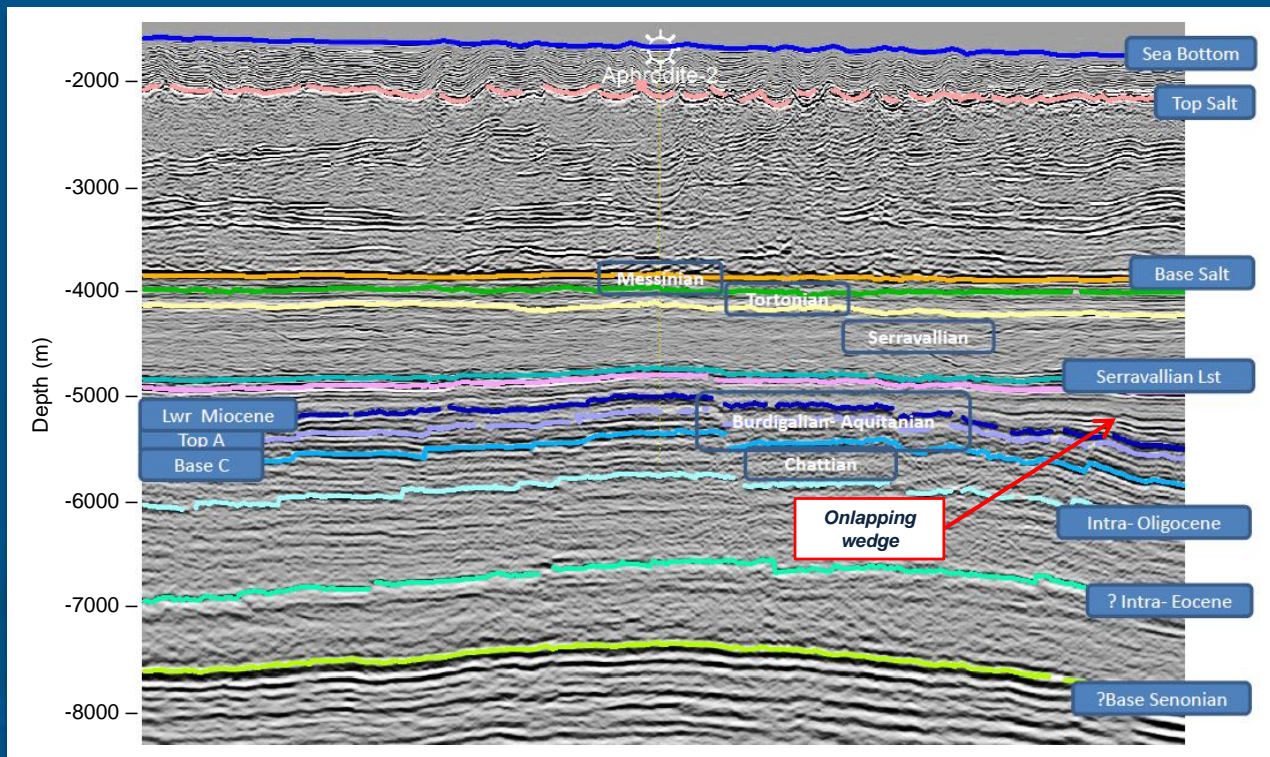
# Line A (dip) flattening on Base C Sand



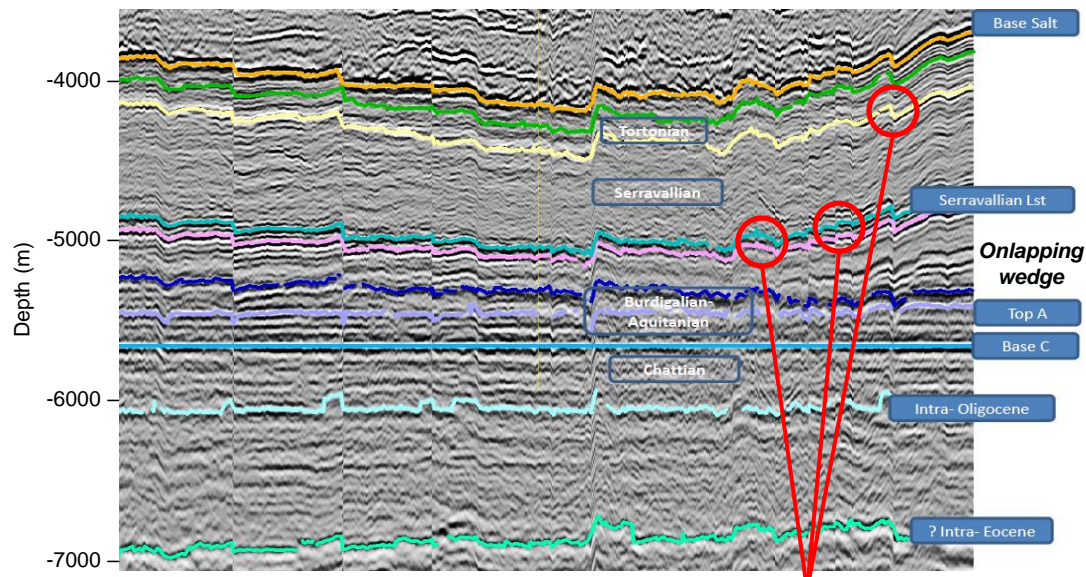
# Line A (zoom) flattening on Base C Sand



# Line B (Strike)



# Line B (zoom) flattening on Base C Sand



NW-SE “piano-key” faults segment the Eocene – Base Messinian salt in Aphrodite (and other “Syrian Arc II structures”). Vertical displacement across piano key faults in Aphrodite are typically tens of metres. Displacement dies out within the (ductile) Eocene interval. There is no evidence of syn-sedimentary growth on these faults which implies they formed abruptly at the start of the Messinian salinity crisis. (Kosieta 2012).

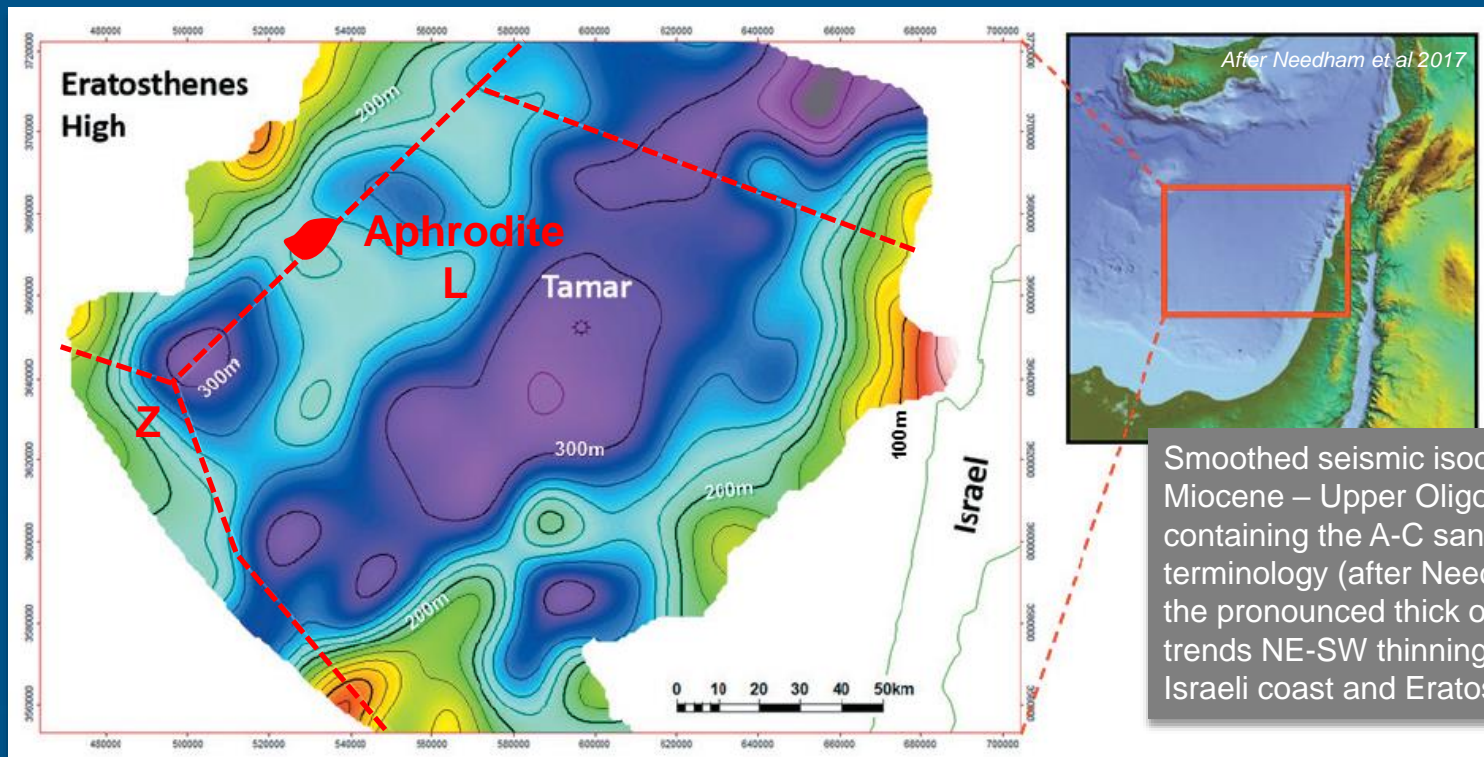
Structuring (thickness variations observed) immediately above “A” Sand.

A compressive event is recorded by an unconformity between Burdigalian and Serravallian (Langhian missing) in Aphrodite-2.

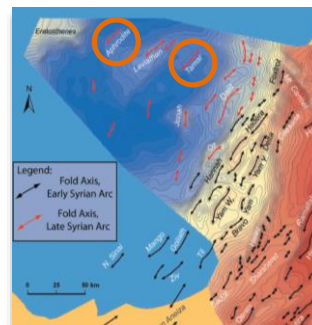
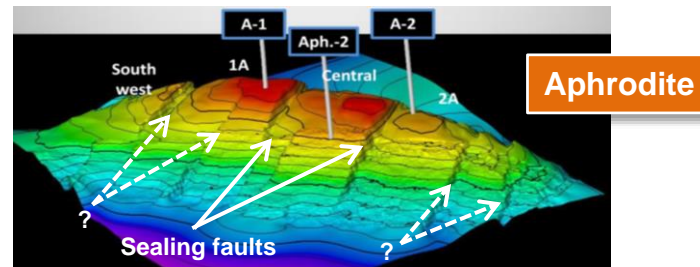
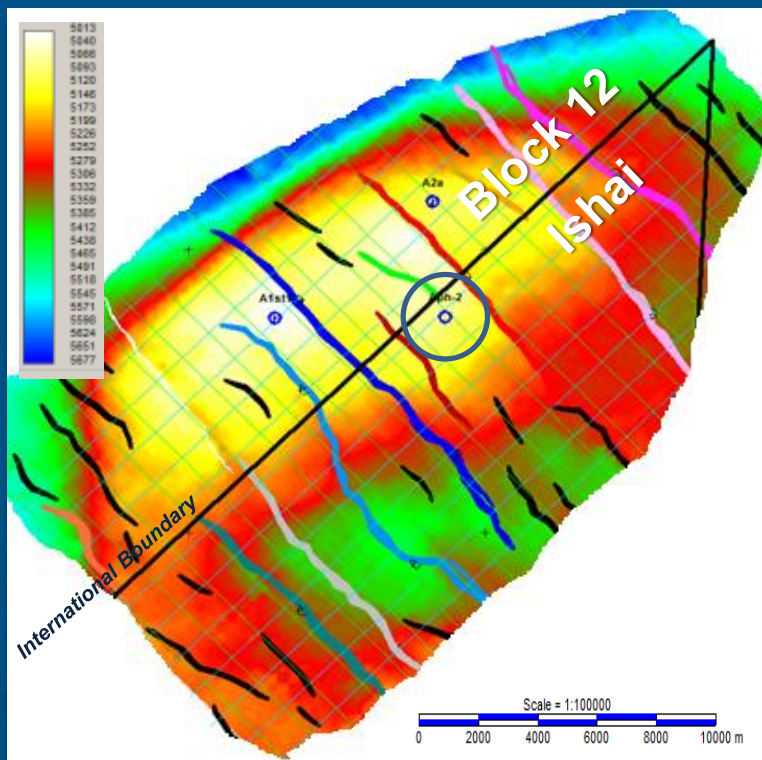
The area was tectonically passive by the time of Serravallian limestone deposition (prominent and continuous seismic horizon).

The onset of tectonic activity coincides exactly with cessation of sandstone deposition in Aphrodite-2 suggesting a regional structural control on sedimentation.

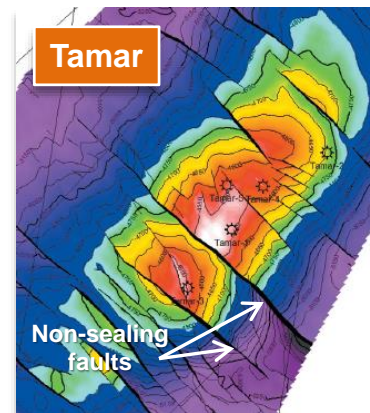
# Oligo-Miocene Gross Thickness



# Aphrodite-Ishai Structure



Aphrodite and Tamar structures shown at same scale



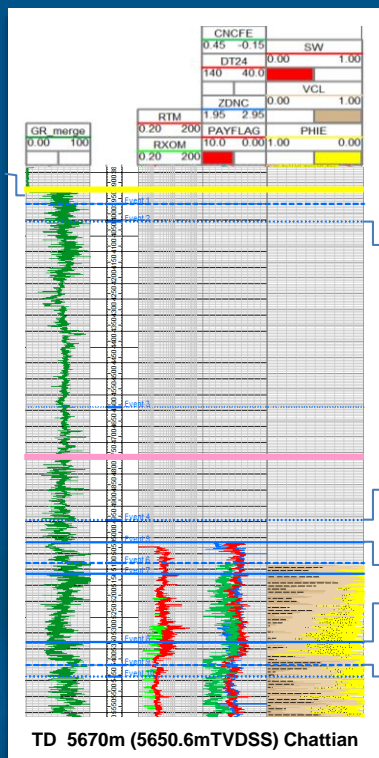
# Aphrodite-2

Ten biostratigraphic  
“Events” recognized  
in Aphrodite-2

Inner neritic – hypersaline  
Open marine – outer neritic  
Open marine –  
mid-upper bathyal  
Open marine –  
outer neritic

Open marine – outer  
neritic – upper bathyal

Open marine – outer  
to middle neritic



Event (2) Middle Miocene

Event (4) Basal Mid. –  
Top Early Miocene

Event (5) Early Miocene

Event (8) Basal Early  
Miocene – ?latest Oligocene

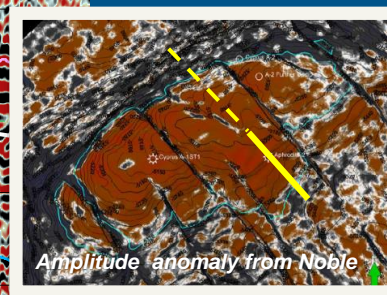
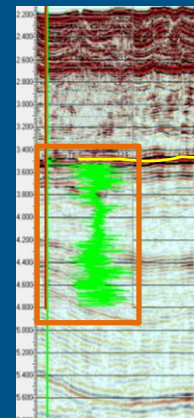
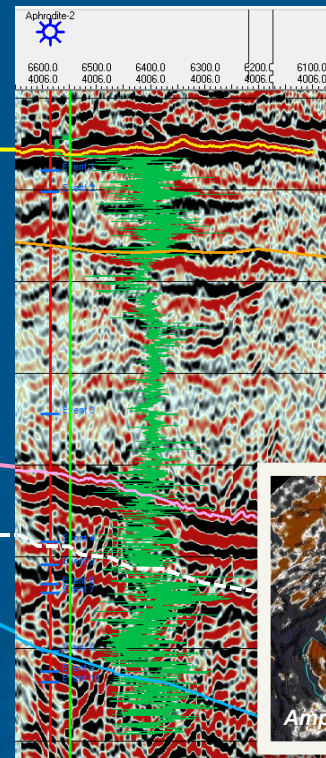
Event (9)  
Late Oligocene

Base  
Messinian  
Salt

Top  
Serravallian  
Limestone

unconformity

Base  
“C” Sand



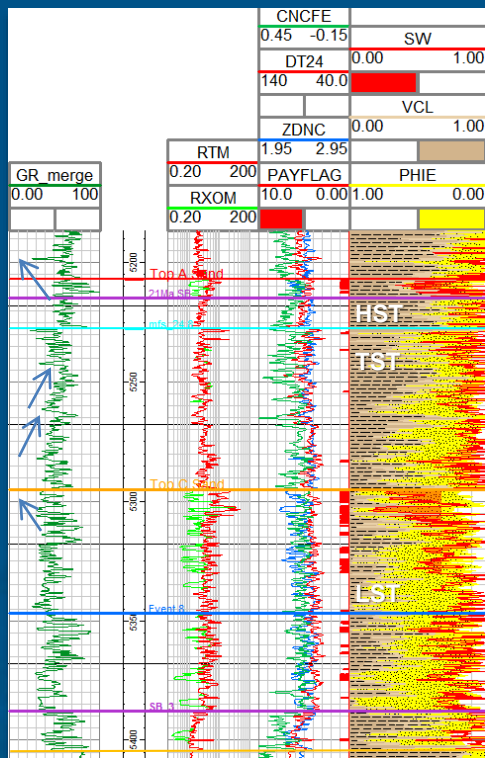
# Event Stratigraphy (Nannofossils)

Event	Age	Characteristics
Event 1	Late Miocene	F.D.O. of small <i>Helicosphaera</i> species and/or <i>M. convallis</i>
Event 2	?Middle Miocene	L.D.O. of <i>Sphenolithus abies</i> and/or <i>Sphenolithus neoabies</i>
Event 3	?Middle Miocene	Increase in the abundance of <i>Reticulofenestra</i> species together with increase in <i>Coccolithus pelagicus</i>
Event 4	Basal Middle to top Early Miocene	F.D.O. or <i>in situ</i> F.D.O. of <i>Sphenolithus heteromorphus</i>
Event 5	Early Miocene	Increase recovery/onset of common <i>Sphenolithus heteromorphus</i>
Event 6	Early Miocene	Base Increase recovery/onset of common <i>Sphenolithus heteromorphus</i>
Event 7	Early Miocene	F.D.O. or <i>in situ</i> F.D.O. of <i>Sphenolithus belemnos</i>
Event 8	Basal Early Miocene to ?latest Oligocene	Increase recovery/onset of common <i>Cyclicargolithus floridannus</i>
Event 9	Late Oligocene	base of common <i>Cyclicargolithus floridannus</i>
Event 10	Indeterminate ?Late Oligocene	Marked reduction in nannofossil density

Biostratigraphic events have varying degrees of confidence but were recognized and correlated with offset wells.

Within the Late Miocene and most of the Middle Miocene few events were recognized and these are of low quality and poorly correlative. The main reason for the low number of correlative events is extensive reworking of this interval that made determination of true marker events uncertain. In combination with wireline response and lithology these events can be integrated in a sequence stratigraphy.

# Aphrodite-2



## Method

Peaks in micro and nannofossil abundance can be used to locate intervals of condensed sedimentation which when integrated with lithofacies and wireline enable recognition and dating of maximum flooding surfaces (mfs). Conversely, abundance minima and changes in micro fossil assemblage character are characteristics associated with sequence boundaries.

Top Aquitanian (5138m) at the 18.5Ma mfs. [= 20Ma boundary of Haq (1987).

Top pay sand "A" interpreted to overlie the 21Ma sequence boundary

?SB4 (21Ma) Intra - Aquitanian Unconformity

Mfs (24.8Ma)

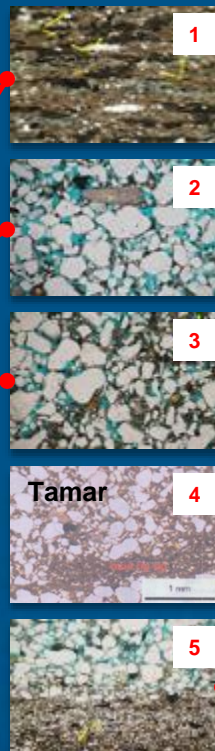
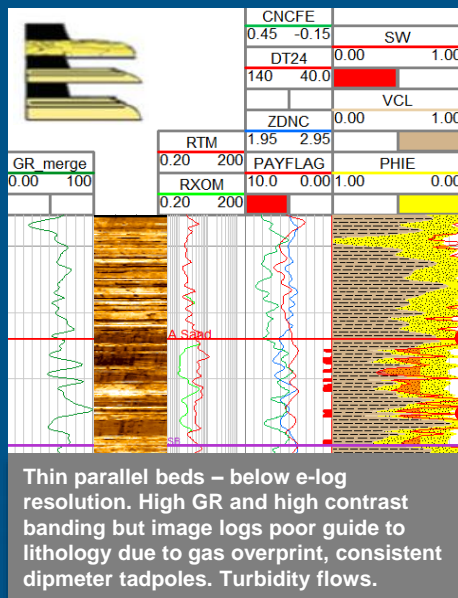
Planktonic foraminifera, the dominant component of the microfaunal assemblage imply normal open marine **outer neritic to upper bathyal palaeoenvironments**. Sparse calcareous benthic forams (Ammonia) indicate transport from shallower realms by gravity flow processes.

"C" Sand (Noble's Tamar terminology) occurs at topmost Chattian  
RPS analysis of Aphrodite-2 placed top Oligocene (25.2Ma) below Event 8

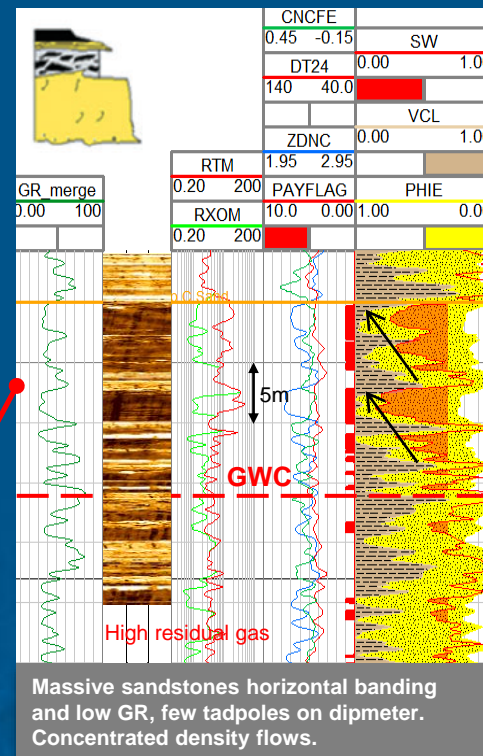
Onset of common recovery *Cyclocarolithus floridannus* -Basal Early Miocene to ?latest Oligocene

SB3 (Un-dated)- lies between nannofossil events 8 & 9, identified from e-log character, specifically neutron-density separation indicative of greater shale content below boundary

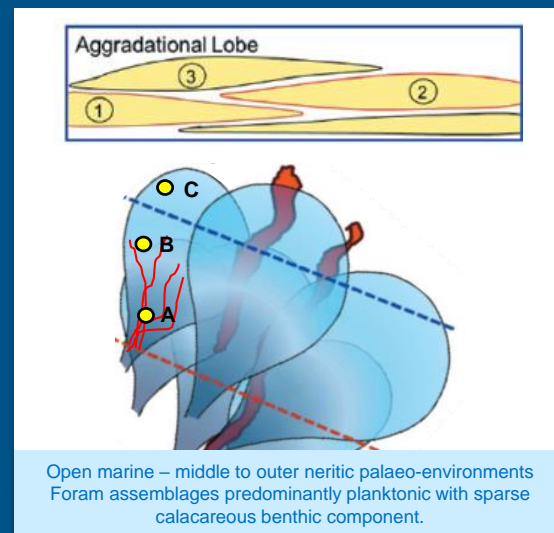
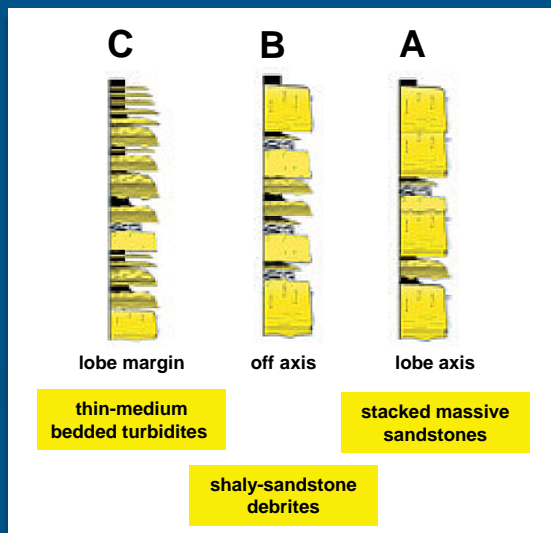
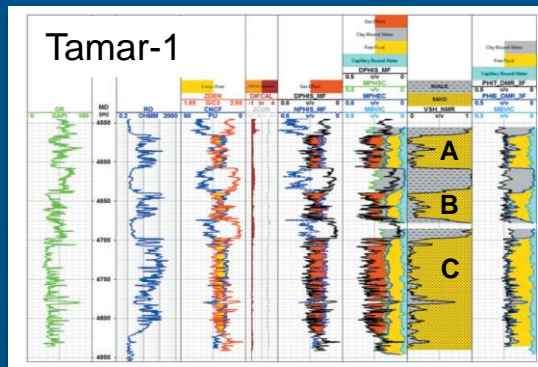
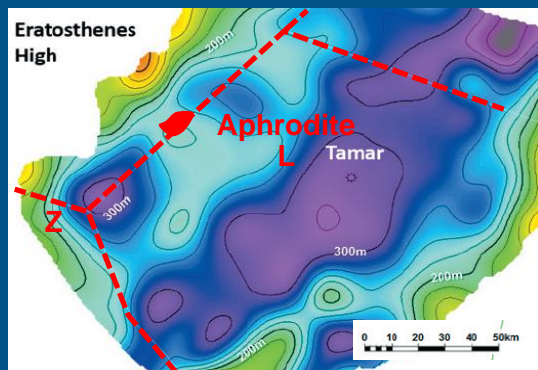
# Aphrodite-2: Gas Reservoirs



1. Silty Claystone: He porosity 11.9% Vis porosity –nil
2. Sub Arkosic Arenite: He porosity 16.4% Vis porosity 17%
3. Sub Arkosic Arenite: He porosity 16.3% Vis porosity 13%
4. Sub Arkosic Arenite (dispersed pore filling shale Tamar field) Christensen 2013
5. Quartz Arenite (mg) Vis porosity 23% contact with arkosic wacke (vfg) , Vis porosity – nil



# Depositional Model



Large scale sediment input to the Levant basin with deposition of prograding and aggrading sediment lobes in an unconfined deep water setting.

Decreasing N/G towards lobe margin with reducing sand amalgamation (Kv barriers increasing), but excellent bed continuity (Kh).

*Modified from Needham et al 2017*

# Summary

- Well Aphrodite-2 (Israel) discovered dry (biogenic) gas in stacked Lower Miocene – Oligocene sandstones.
- Biostratigraphic events identified in Aphrodite-2 were integrated with lithofacies and wireline data to develop a sequence stratigraphic framework for this deep water (middle-outer neritic to upper bathyal) setting.
- Sequences (third order) were calibrated to published zonation schemes (eg. Armentrout 1996 and Emery & Myers 1996) and to the Sea level curve of Haq 1987.
- 2D regional and 3D seismic data constrains the timing of structural development to short-lived events, Burdigalian – ?Langhian and Early Messinian.

# Conclusions

- Aphrodite is a large accumulation of dry (biogenic) gas that straddles the international boundary between Israel and Cyprus.
- Burdigalian – ?Langhian compression gave rise to large NE-SW trending “Syrian Arc-II” inversion anticlines in the Levant basin offshore Israel.
- The Early Messinian was associated with more widespread orthogonal “piano-key” faulting possibly associated with the onset of the Messinian salinity crisis.
- Onset of Burdigalian deformation coincided with cessation of sand deposition at Aphrodite suggesting an over-riding tectonic control on reservoir sand distribution within the Levant basin.

## Conclusions (cont.)

- Aphrodite reservoir sands were deposited in unconfined lobes and form an aggradational stacked sequence marginal to the main axis of deposition in the Levant basin. Sand beds exhibit excellent horizontal continuity.
- The reservoirs comprise medium-fine grained, generally poorly sorted quartz arenites and sub-feldspathic arenites deposited by turbidity currents. They exhibit good-fair poroperm character.
- The development of the Aphrodite structure was simultaneous with other gas-bearing structures within the Levant basin and provides a bench mark for basinwide analysis if and when more well information is released in future.
- The reasons for deformation being mainly confined to Late Early Miocene (Burdigalian) remain unclear.