The Importance of Multi-Scale Petroleum System Assessment for Plays and Prospects De-Risking in the Eastern Mediterranean Basin*

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Abstract

Identifying the potential geological risks before drilling leads and prospects is a common practice for E&P operator companies. Traps and reservoir quality often receive the main attention during risk assessment. However, in the Eastern Mediterranean the biogenic gas sources generation, the synchrony between trap formation and hydrocarbon charge, and more important, the hydrocarbon preservation related to the large-scale hydrodynamics of the basin, are less analyzed or understood. A key element in the Eastern Mediterranean mega basin is the assessment of the biogenic gas potential, both in term of generation but also of preservation in the geological system. The effectiveness of biogenic gas systems is mainly controlled by the past thermal gradients and sedimentation rates. Contrarily to conventional source rocks, significant rock volumes with low organic matter content are likely involved in the biogenic gas generation process. In the deepest parts of the basin, Tertiary biogenic gas source rocks are now undergoing catagenesis. Another key element is the fluid flow history from the core of the Eastern Mediterranean basin toward its margins (including Eratosthenes Sea Mount).

The hydrodynamics is first induced by high sedimentation rates and sediments compaction within the Nile Delta and the Levant Basin during the Oligo-Miocene and Plio-Pleistocene. During the Messinian Crisis short term 1400m sea level drop followed by massive impervious evaporite deposition plays a very important role in the evolution of fluid flow orientation, pressure

gradients, and hydrocarbon migration and dis-migration. The fluid flow is also controlled by the presence of a relatively well-connected pressure unit in Oligo-Miocene sands throughout the Levant Basin. Active hydrodynamism and buoyancy of biogenic gas are the main factors controlling the hydrocarbon migration mechanisms. A lateral long distance up-dip fill-and-spill migration is observed. Therefore, a more complete understanding of the petroleum system behavior is achieved by recognizing the origin of the geochemical and physical phenomena occurring in the subsurface, in a regional or semi-regional basin scale. It will allow recognition of the hydrocarbon generation and the pore pressure and fluid flow regime patterns, which are not caught at limited prospect scale. Basin modeling techniques offer the possibility to estimate the heating rates of sedimentary basins, the timing, and quantities of generation of biogenic or thermogenic hydrocarbons and, finally the pore pressure-effective stress regimes responsible, in part, for the hydrocarbon migration and effective charge.

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The importance of multi-scale petroleum system assessment for plays and prospects de-risking in the Eastern Mediterranean Basin

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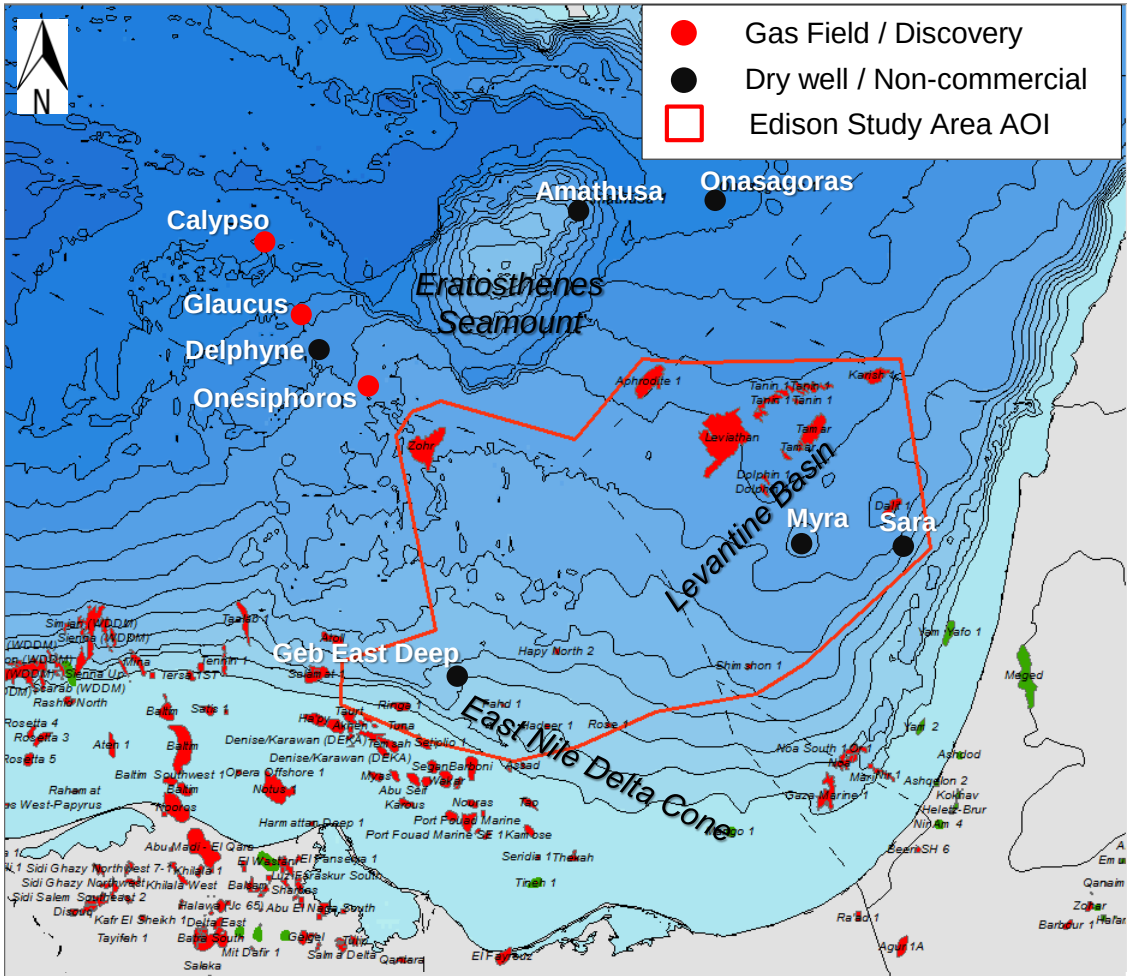
Introduction



- What geological factors are controlling the success or failure of finding economic gas volumes in the East Mediterranean Basin?

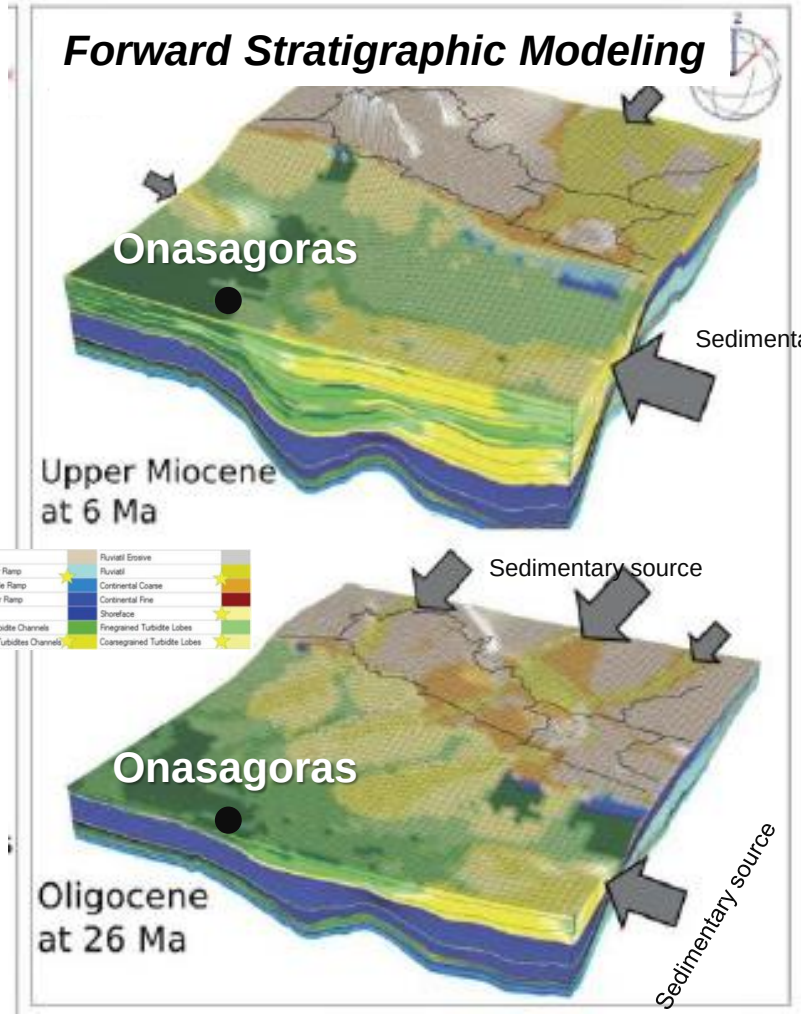
- Which are the main geological risks to identify in order to avoid dry wells?

Objective:

- Recognize the importance of multi-scale petroleum systems evaluation to identify the potential geological risks in prospects/leads before drilling

- Main associated risks :
  - Facies distribution (RES, SR…)
  - Adequate thermal regimes responsible for biogenic gas generation/preservation
  - Fluid flow regimes responsible of the HC migration/preservation or loss

Facies distribution at regional scale
Reservoir and Source Rock presence



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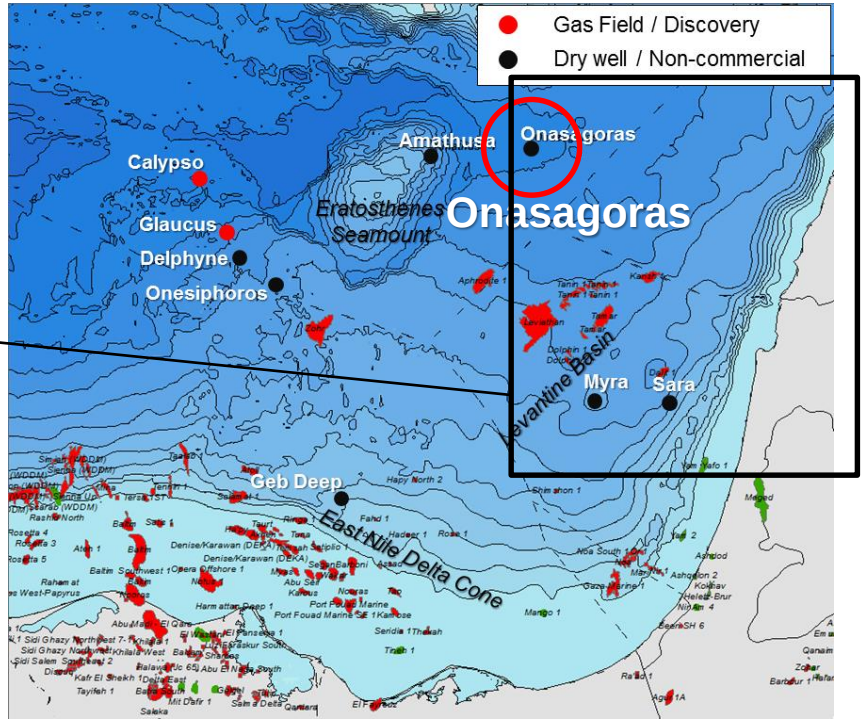


ONASAGORAS dry/non-commercial well:

- Low quality reservoir shale/silt in Miocene
- Basin sand lobe controlled by paleobathymetry low
- Limited sand provenance and/or shelf by-pass

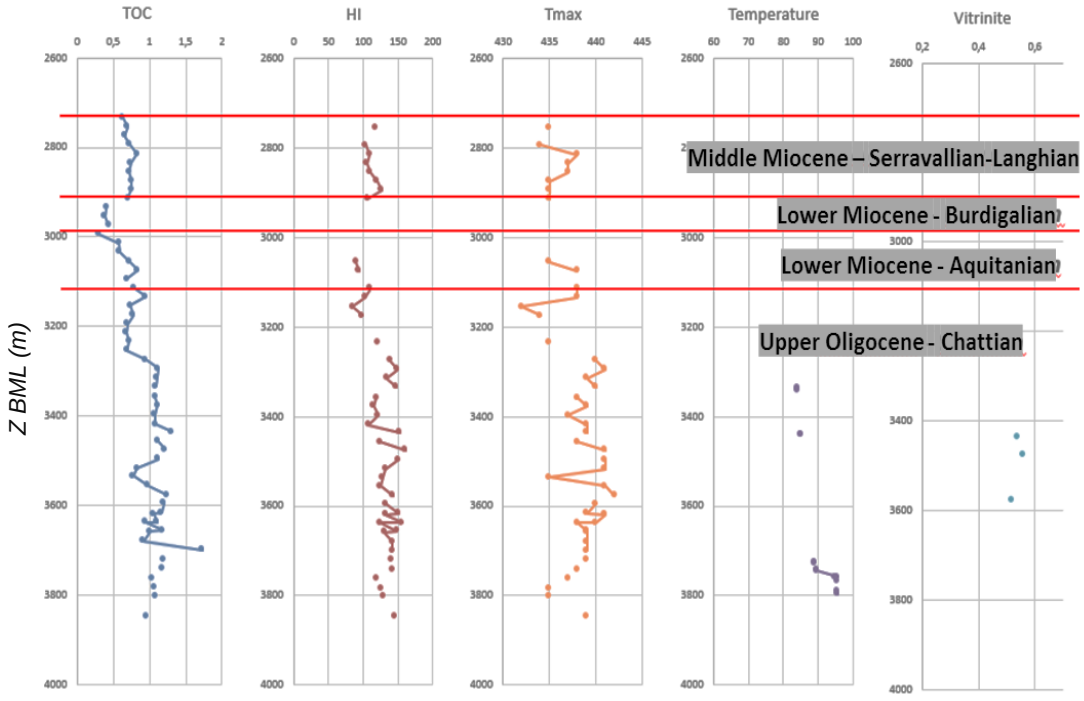
→ **Delineate the geological risks**

→ **Populate the basin model**

Tertiary Source Rock Potential
Well data

Source Rock		Type	Net Thickness	Av. Initial TOC	Av. HI
			m	%	mg/g
Pliocene	Zanclean	Biogenic Terrestrial	200 - 800	0.7%	< 100
Middle Miocene	Tortonian - Langhian	Biogenic Terrestrial	500 – 1500	0.8%	100
Lower Miocene	Aquitanian	Biogenic Terrestrial	200 - 500	0.8-1.0%	100
Oligocene	Chattian - Rupelian	Biogenic / Thermogenic Terrestrial	1000 - 1800	1.3-1.5%	150

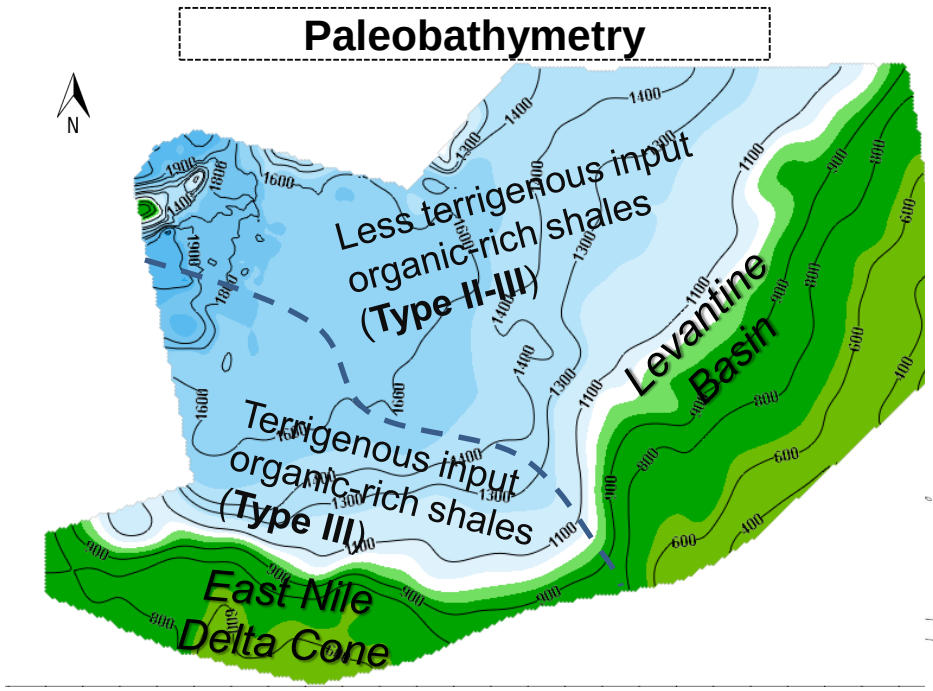
Rock Eval – deep water Nile Delta well

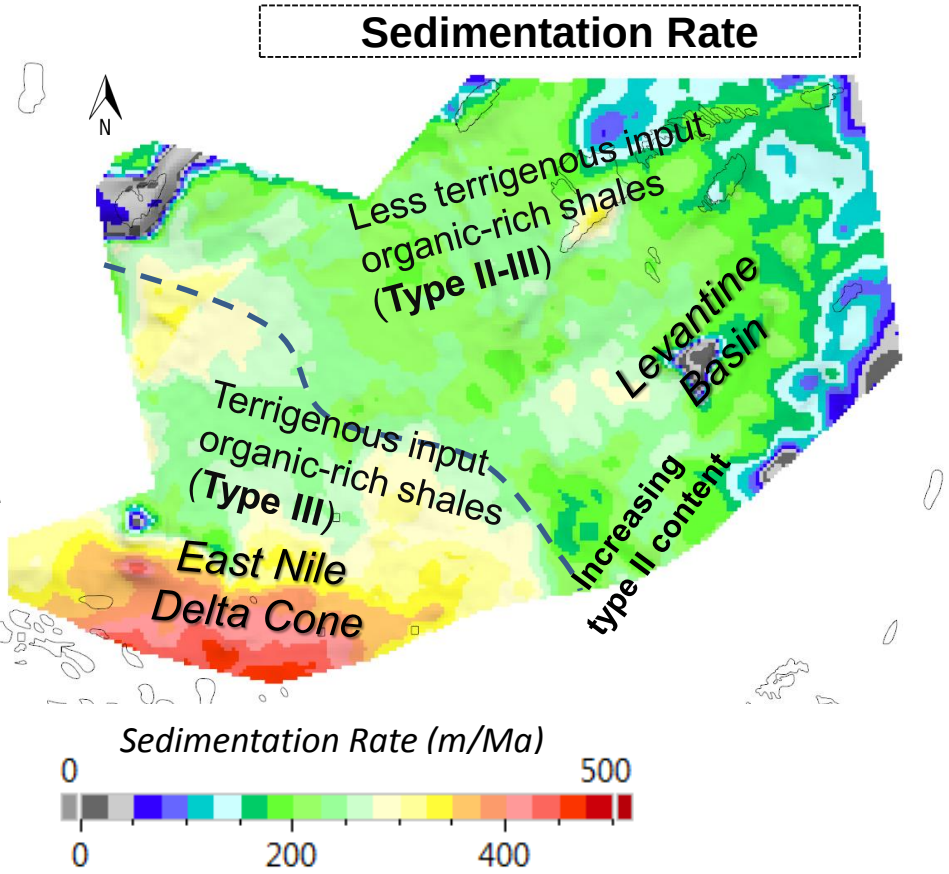


- Low TOC : 0.7 to 1.3 %
- Hydrogen Index (HI) : 100-150 mg/g
- TOC & HI higher in **Upper Oligocene**
- Kerogen : Type III terrestrial dominant
- Net Thickness = 200 // 1000 m

Initial potential for biogenic methane generation (and in a lesser extent for thermogenic gas)…
But biogenic gas generation and preservation depends also on thermal gradients and **sedimentation rate** *(clayton,1992; Schneider et al., 2016)*

Depositional Context
Example Oligocene Source Rock

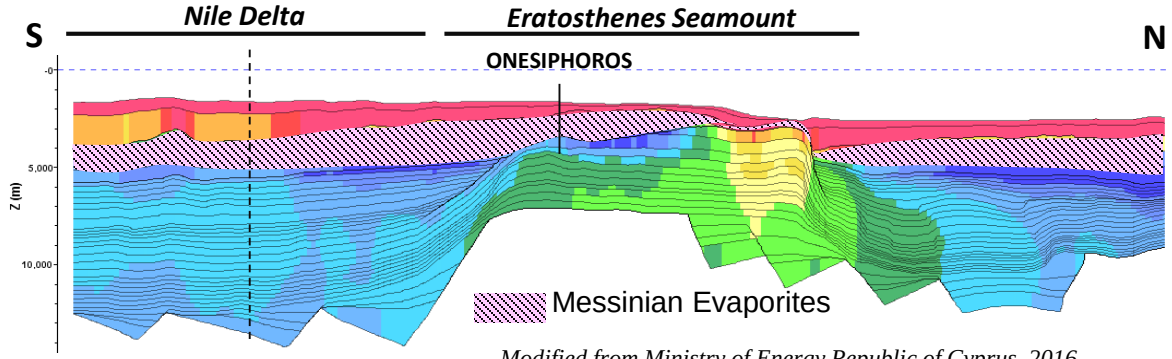




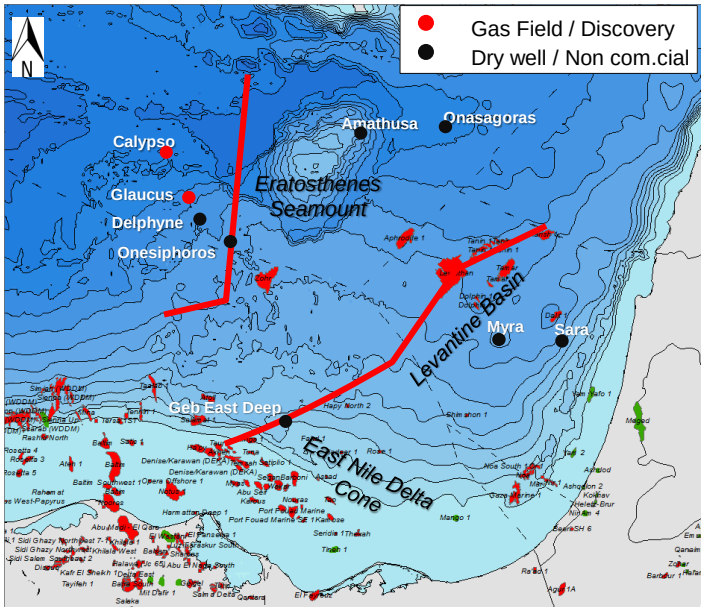
- **Forward stratigraphic modeling** is useful to predict terrestrial/marine organic matter content and distribution
- Main source of sediments and organic matter from Nile Delta (terrestrial organic matter)
- Less terrestrial organic matter in Levantine basin, probably mixed with marine organic matter
- High sedimentation rate favorable to biogenic gas generation and preservation

Regional thermal gradient regime
Basin modeling result

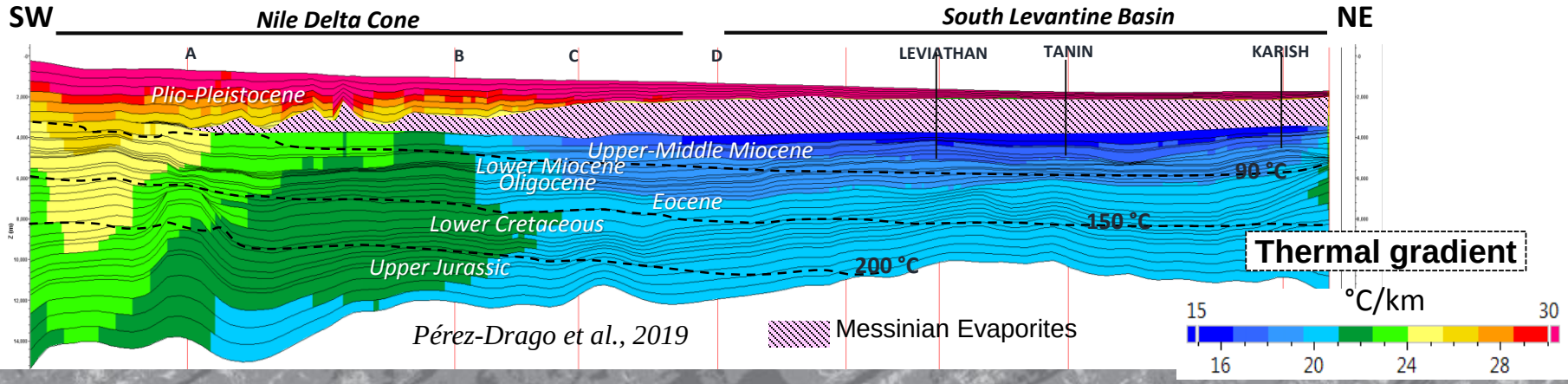
Thermal gradient



Modified from Ministry of Energy Republic of Cyprus, 2016



- Thermal boundary conditions computed with a **regional lithospheric model,** extremely efficient for predicting the thermal regime far from the well at present day and in the past.
- **Low thermal gradient** (<20 °C/km) below Messinian Evaporites
- Lower Miocene and Oligocene **above 90°C** at present day…



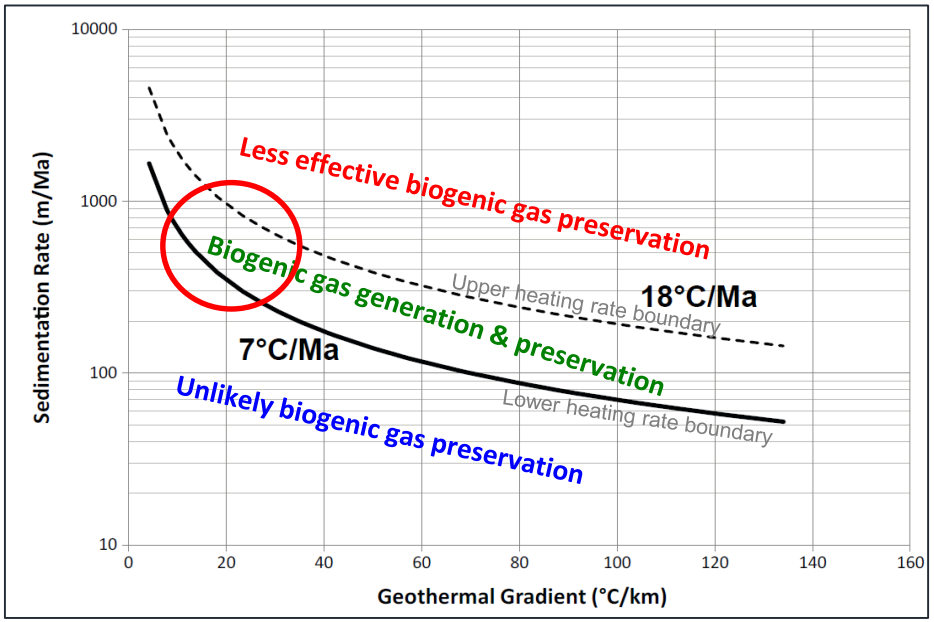
Pérez-Drago et al., 2019

Biogenic Gas Generation/Preservation Conditions

The biogenic gas generation/preservation potential depends on:

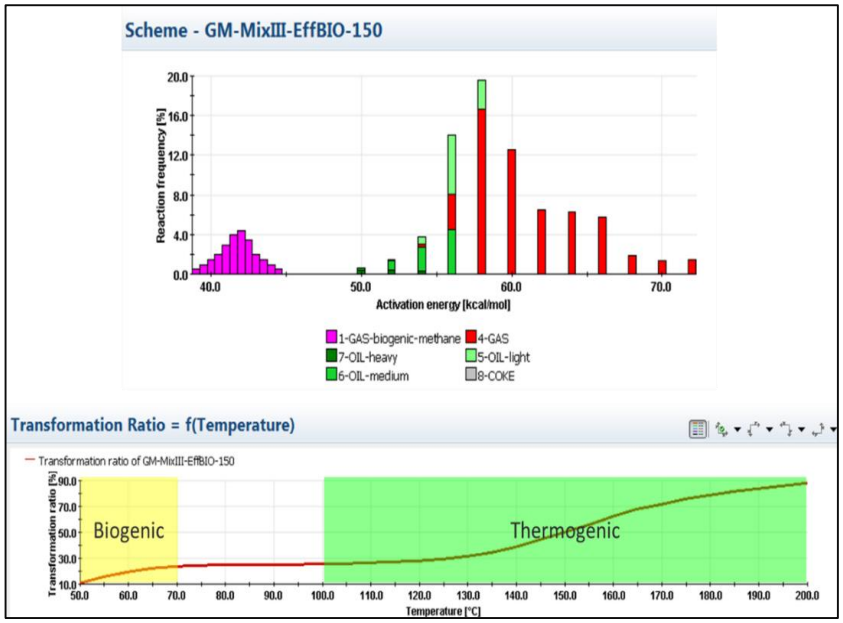
- ✓ Organic matter content
- ✓ Heating rates (sedimentation rates * thermal gradients)

Biogenic gas window empirically defined between
heating rates ~ 7 and 18 °C/Ma



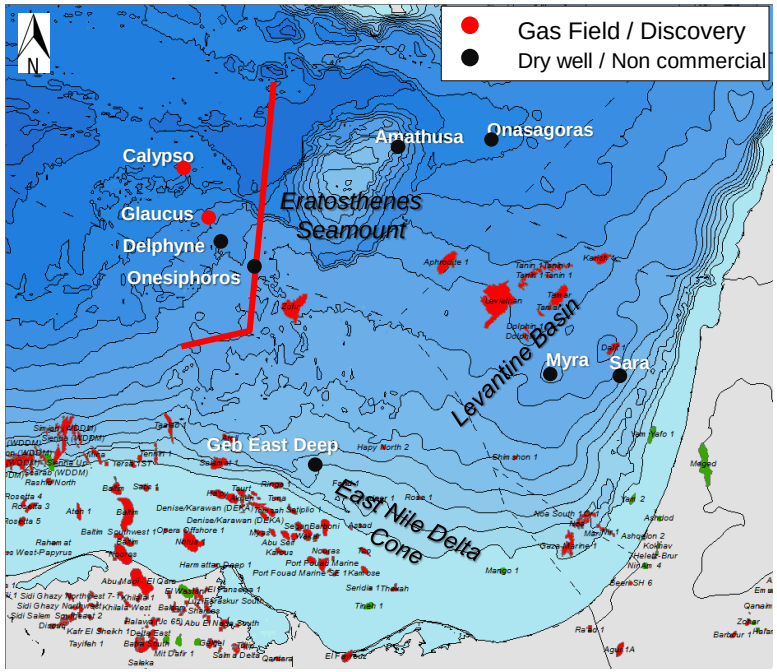
Clayton, C., 1992
Schneider et al., 2016

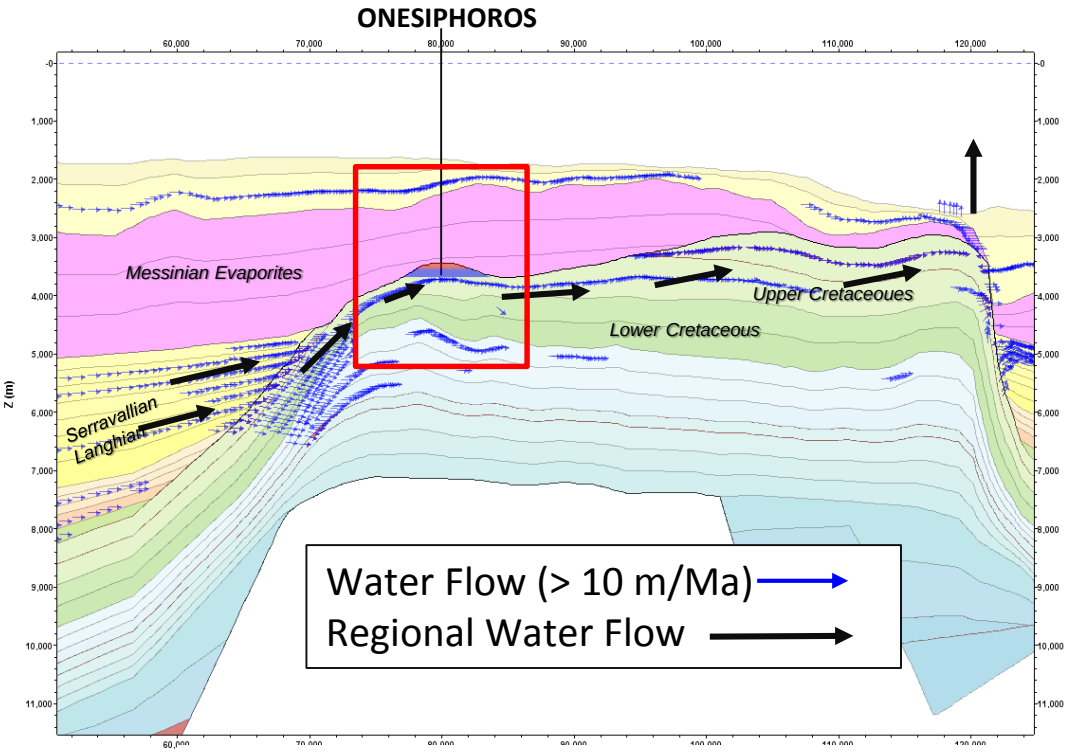
Biogenic to thermogenic kinetic scheme



Same source rock generating first biogenic gas and then thermogenic hydrocarbons (e.g. in Nile Delta)

Hydrodynamism - Fluid Flow Regime Eratosthenes



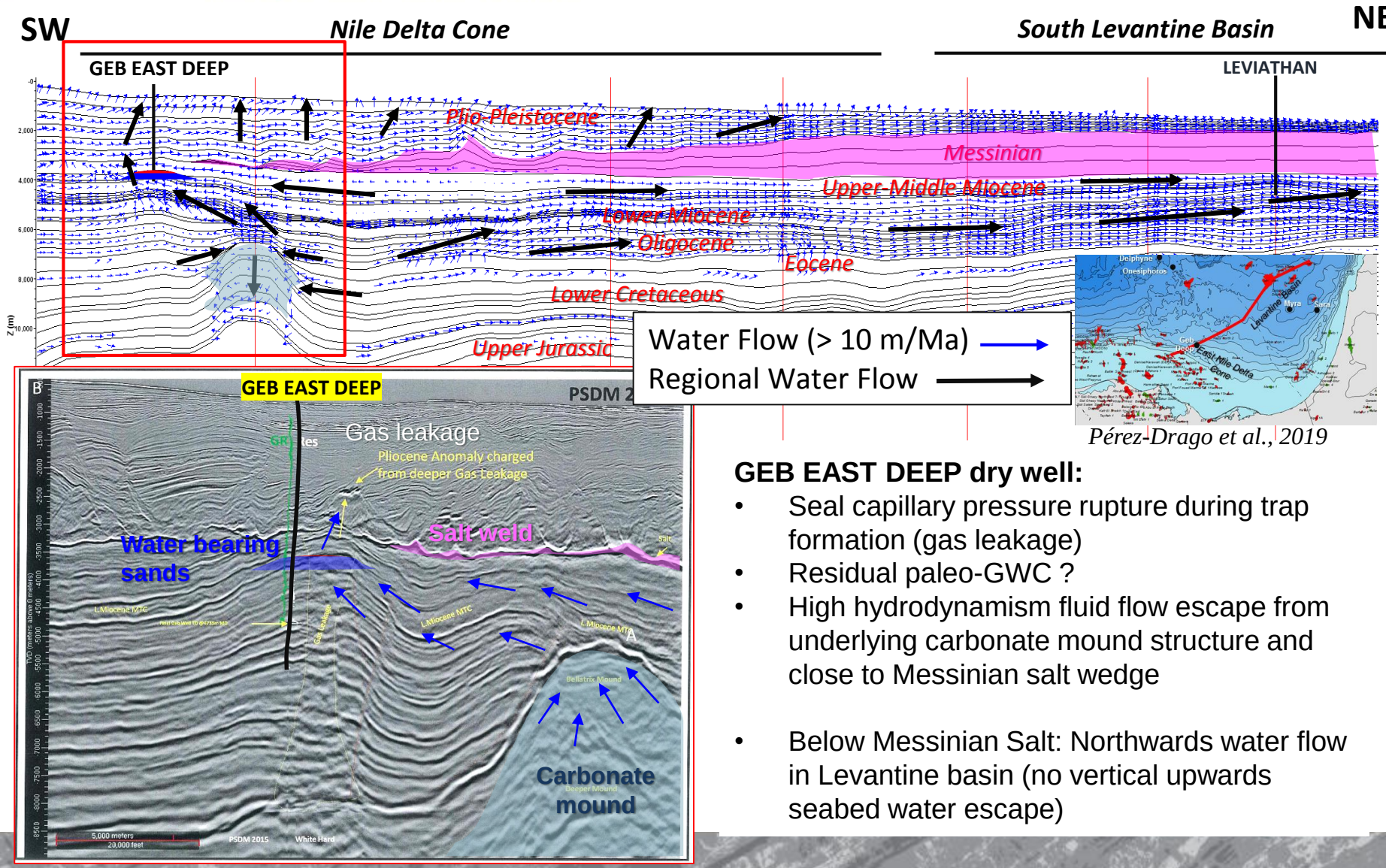


Modified from Ministry of Energy Republic of Cyprus, 2016

ONESIPHOROS gas/non-commercial well:

- Low quality carbonate reservoir (Upper Cretaceous)
- Average quality structural closure ?
- Residual paleo-GWC
- High hydrodynamism up-dip fluid flow escape below Messinian salt towards ESM

Hydrodynamism - Fluid Flow Regime
Nile Delta & Levantine basin



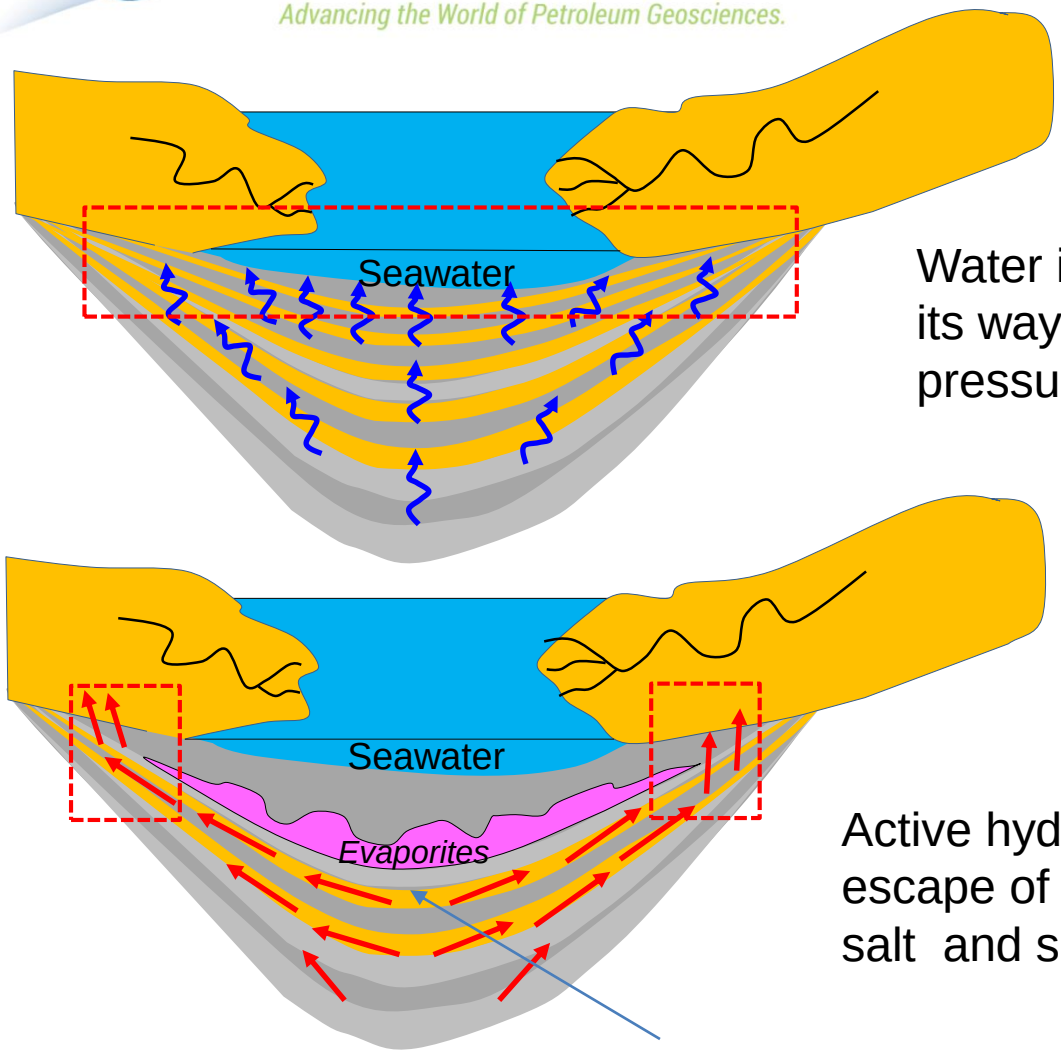
Pérez-Drago et al., 2019

GEB EAST DEEP dry well:

- Seal capillary pressure rupture during trap formation (gas leakage)
- Residual paleo-GWC ?
- High hydrodynamism fluid flow escape from underlying carbonate mound structure and close to Messinian salt wedge

- Below Messinian Salt: Northwards water flow in Levantine basin (no vertical upwards seabed water escape)

Hydrodynamic basin settings



Water is expelled from sediments and finds its way towards the surface. Normal pressurized system.

Hydrostatic normal compaction dewatering flow

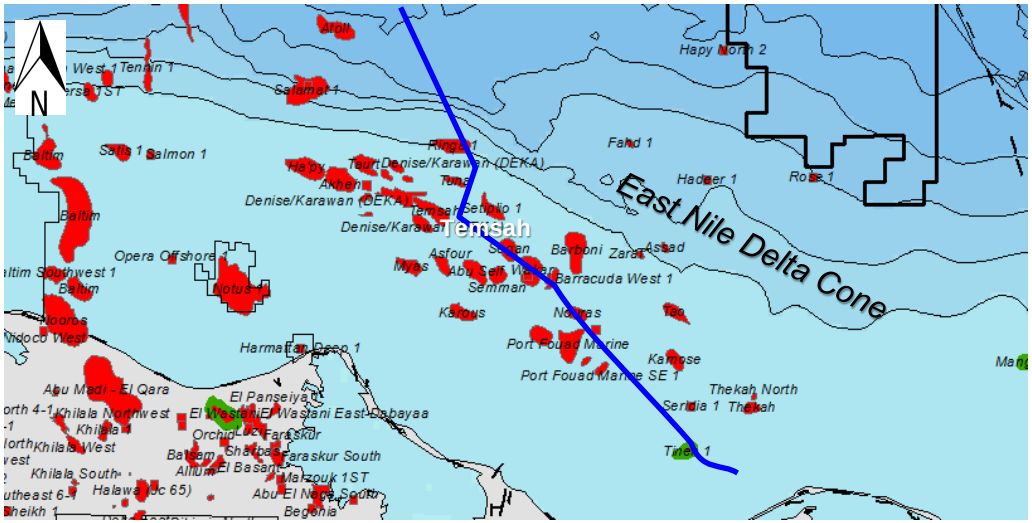
Over-pressured water flow

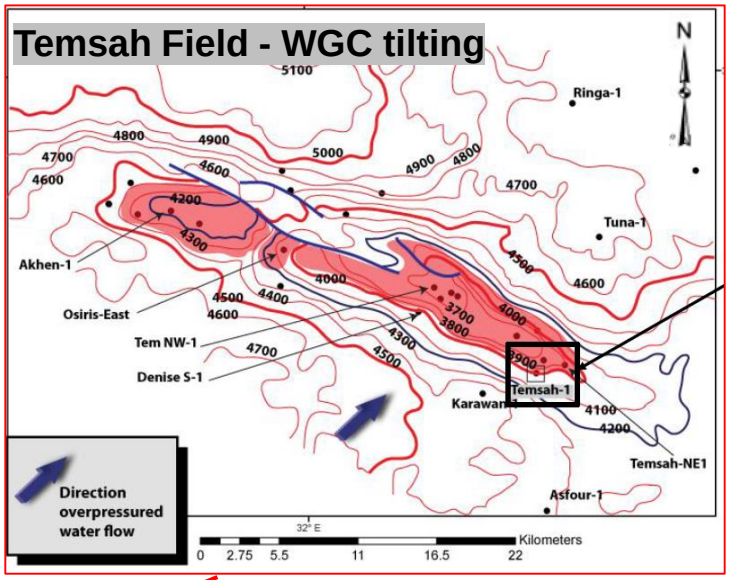
Water surface escape area

Active hydrodynamism controlled by lateral escape of over-pressured water flow below salt and shale seals towards the basin edges

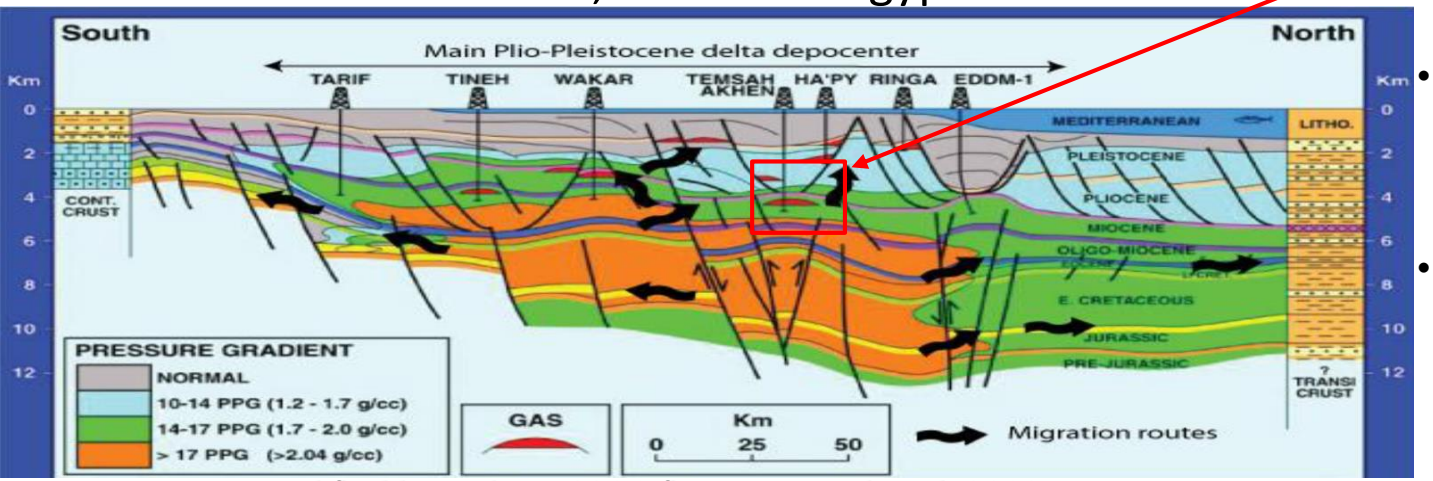
Rather uniform overpressure (~10-15 MPa) in « Tamar Sand » at basin scale

Nile Delta Hydrodynamics





Pressure Profile Schematic, Nile Delta Egypt

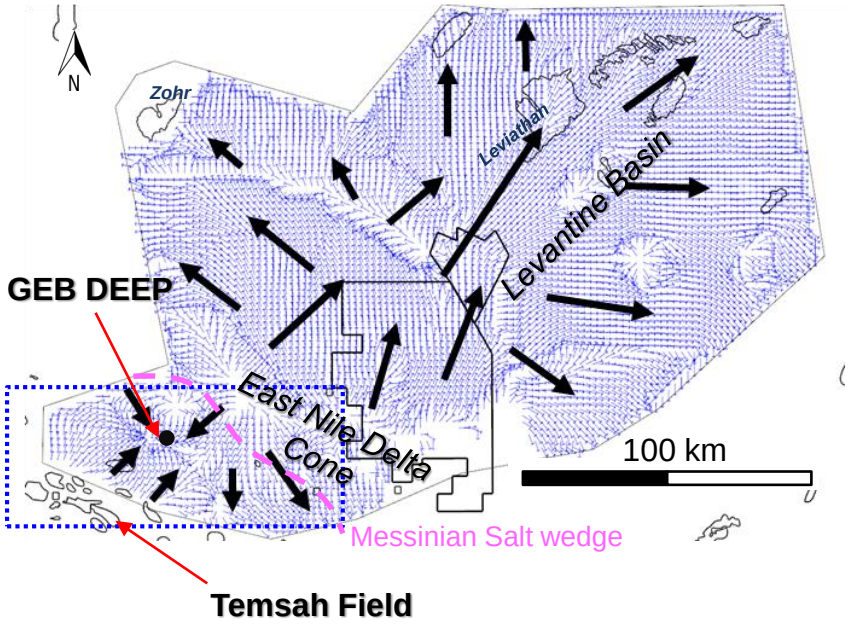


Modified by Dolson, 2016, from Heppard et al, 2000

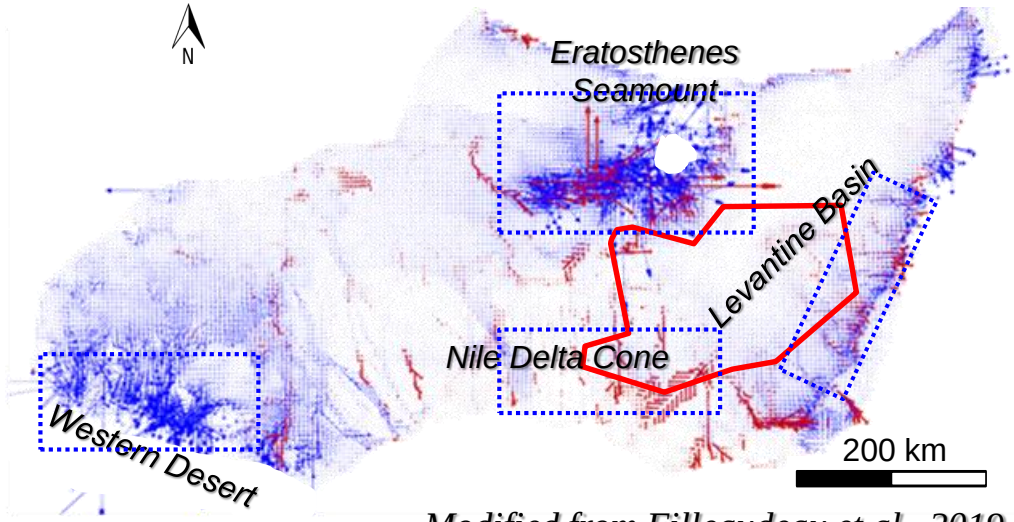
- Active hydrodynamism in Nile Delta Temsah trend fields
- Tilted GWC in Temsah field due to northward over-pressured water flow

Hydrodynamism - Fluid Flow Regime Multi-Scale

Semi-regional study Water Flow



Regional study Water Flow

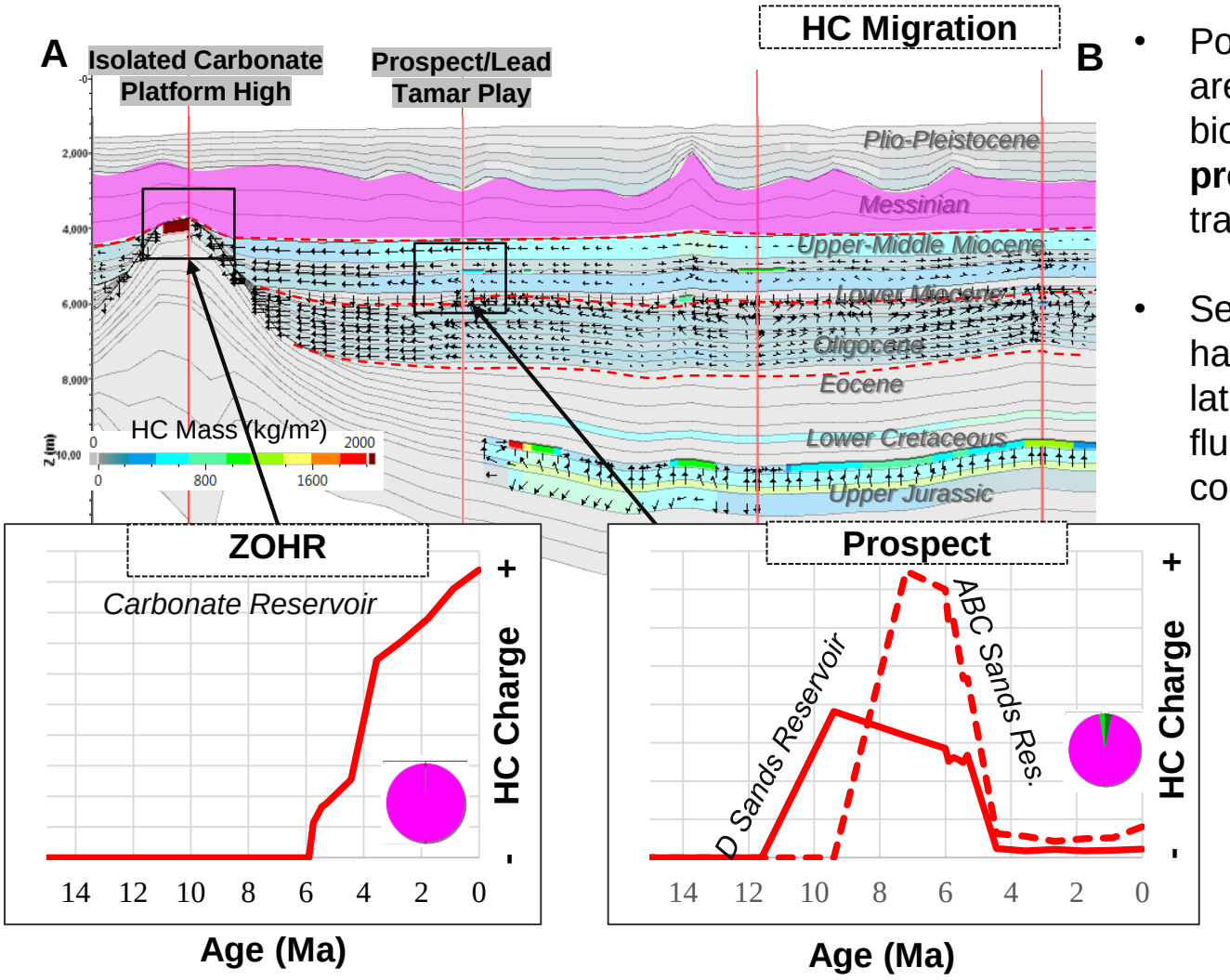


Modified from Filleaudeau et al., 2019

Water Flow (> 10 m/Ma)
Regional Water Flow
Highly active hydrodynamism

- Active hydrodynamism controlled by lateral escape of over-pressured water flow below Messinian salt towards the basin edges (ESM, Nile Delta salt wedge, Levant Shelf)
- Semi-regional model allows a more detailed knowledge of water flow behavior

Hydrocarbon Charge and Preservation Risk



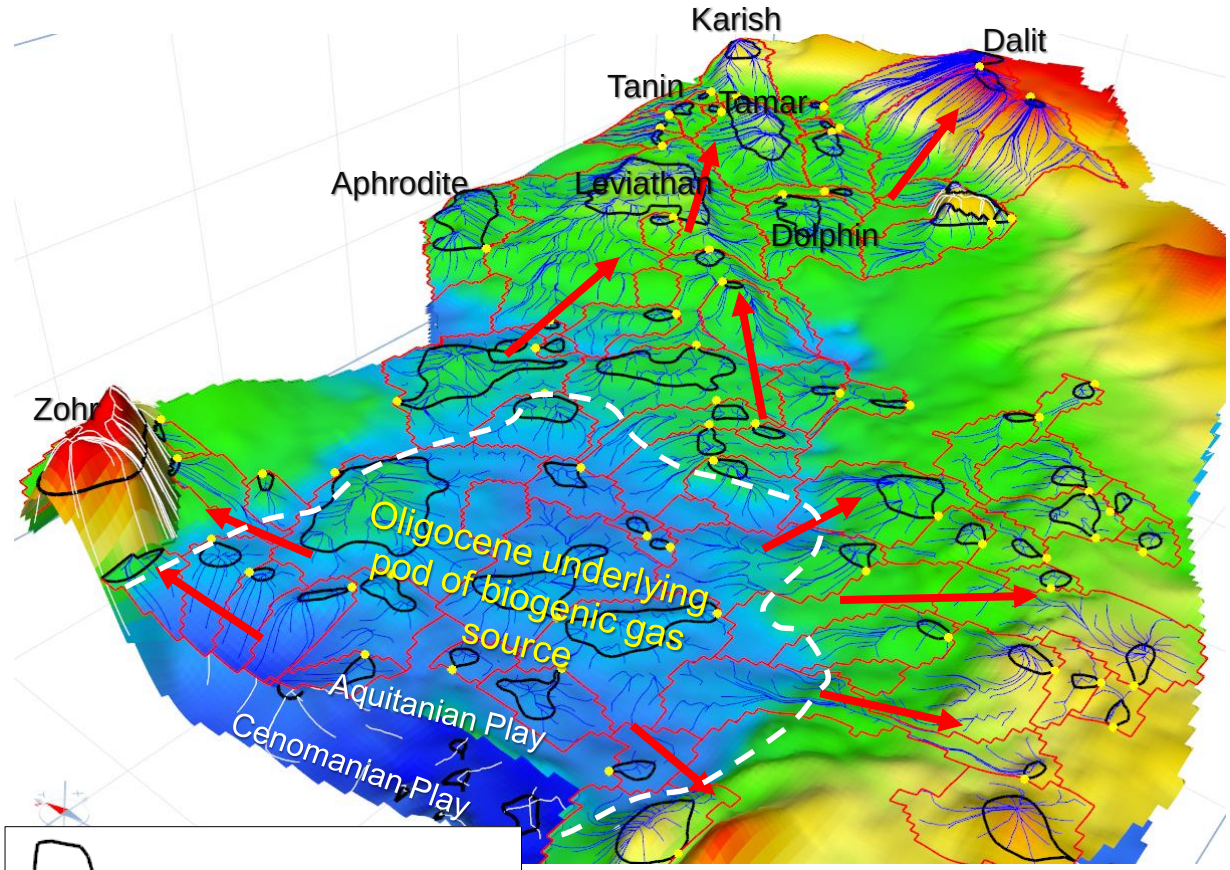
- Pore pressure - fluid flow history are helpful to analyze the risk of biogenic gas migration and **preservation** in the traps/prospects
- Semi-regional models allow to have a higher vertical and lateral resolution to reproduce fluid flow mechanisms and composition

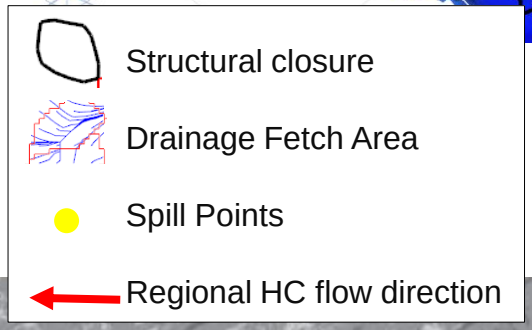
HC Compositional Fractions

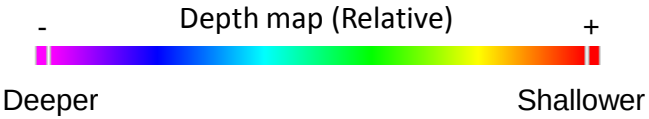
Biogenic CH4

C6+

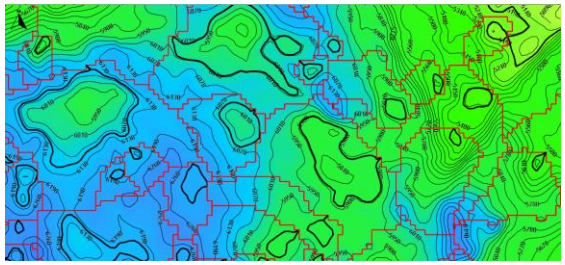
Drainage Area – Trap Fetch Area







- Within hydraulically connected systems, biogenic gas migration mechanisms are mainly controlled by lateral up-dip migration fill and spill chains
- Reservoir pore pressure variations (Messinian Salinity Crisis) modify the fluid flow velocity
- Therefore, hydrodynamism and HC dis-charge (reservoir flushing) represents a major risk for prospect



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Implications and Conclusions

- A complete understanding of the petroleum system behavior is achieved by recognizing the origin of the geochemical and physical phenomena occurring in the subsurface.
- A field scale study (local area) would not be able to understand the fluid flow regimes and HC charge given the important lateral migration distances.
- Multi-scale petroleum systems modeling (semi-regional and regional) allows to identify the potential geological risks regarding pressure fluid flow behavior and HC charge before drilling leads and prospects.

- Biogenic gas generation does not represent a major risk given the favorable thermal and initial organic content conditions of Tertiary sediments.
- However, one of the main risks is the HC preservation due to active aquifer hydrodynamism, inhibiting efficient HC columns preservation with economic volumes.
- Reservoir risk is mainly constrained by sand channel discontinuity in the shelf and basin sand lobes extension. Regional scale forward stratigraphic modeling is valuable in order to understand sedimentary depositional settings and sand/reservoir distribution.
- Hydrocarbon discharge by flushing will be also affected by the geometry and size of the traps.

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