The Messinian Mediterranean Crisis: A Model for the Permian Delaware Basin?*

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Abstract

Basin analysis and high resolution seismic sequence stratigraphy of the Delaware and Egyptian Mediterranean show the Mediterranean Messinian Crisis of evaporate deposition to bear similarities to the Late Permian both on global and regional scales. Comparison of the two basins provides new insight which can assist petroleum exploration in both basins. During the Permian and its close, global sea level was unusually low. In addition to glaciation in the southern Gondwanaland, other contributions to globally low sea level are a globally decreased rate of sea floor spreading and ocean basin water transfer such as that occurred during the closing and opening of the Mediterranean during the Messinian. With such a lowering of sea level, methane hydrate gasification would provide an enormous increase in methane as a greenhouse gas leading to the documented elevation in global temperatures and restricted oceanic circulation. Without shelves for carbonate deposition, a significant transfer of inorganic carbon to organic carbon occurred, and with increased evaporation rates a transfer of reduced sulfur to oxidized sulfur exogenic reservoirs, and oceanic and basinal anoxic conditions led to the preservation of significant amounts of organic carbon which led to the formation of extensive source rocks.

As the sea level continued to fall, and with accompanying Mesozoic Pangea break-up exacerbating localized uplifts owing incipient rifting nuclei, borders to inlets closed and vast aqueous evaporite deposition occurred not only in the Delaware Basin but in numerous basins around the world. With this evaporation, the water was gradually transferred back into the global system and sea level began to rise once again to its preceding levels. Comparison of the Delaware and Mediterranean basins evaporate fill is remarkably similar in salt mineralogical distribution, following an approximate Usiglio sequence away from the inlets (Hovie and Gilbratar, respectively) laterally of calcite, anhydrite, gypsum, and halite. During times of low intrabasinal relative sea level, significant downcutting and fluvial incision occurs with basin floor fan deposition. The subsequent flooding sealed these incised valleys and the Regressive System Tract fluvial terraces in the paleo-Nile Delta. Analogous traps in the Delaware Basin margins for the overlying Triassic-Jurassic have yet to be fully exploited, while analogous deep water fans are continuing to be successfully explored in both basins.

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The University of Oklahoma

A Tale of Two Basins

It was the best of all times*, it was the worst of all times**…

-Charles Dickens, A Tale of Two Cities, 1859

All crises begin the same way, in good times*, and end the same way, in bad times**.

-This paper

**Messinian – bad times

*Tortonian --- good times

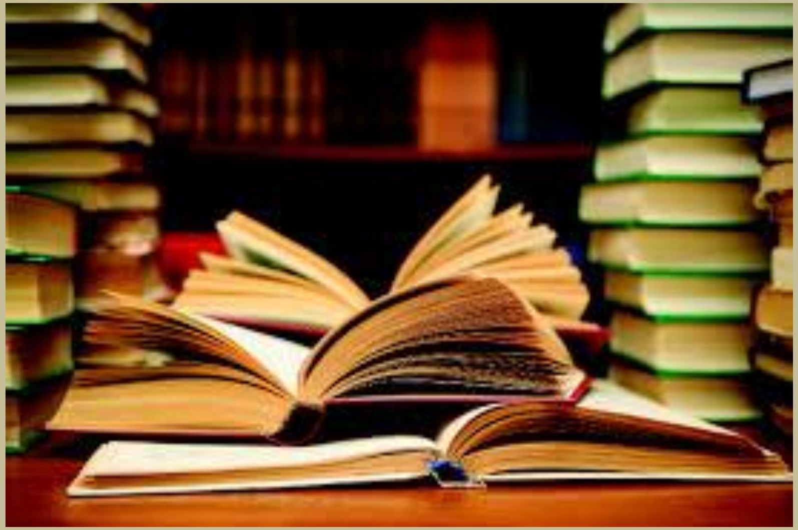
** Ochoan – bad times

*Guadalupian– good times

With apologies to Dickens.

Problem Definition

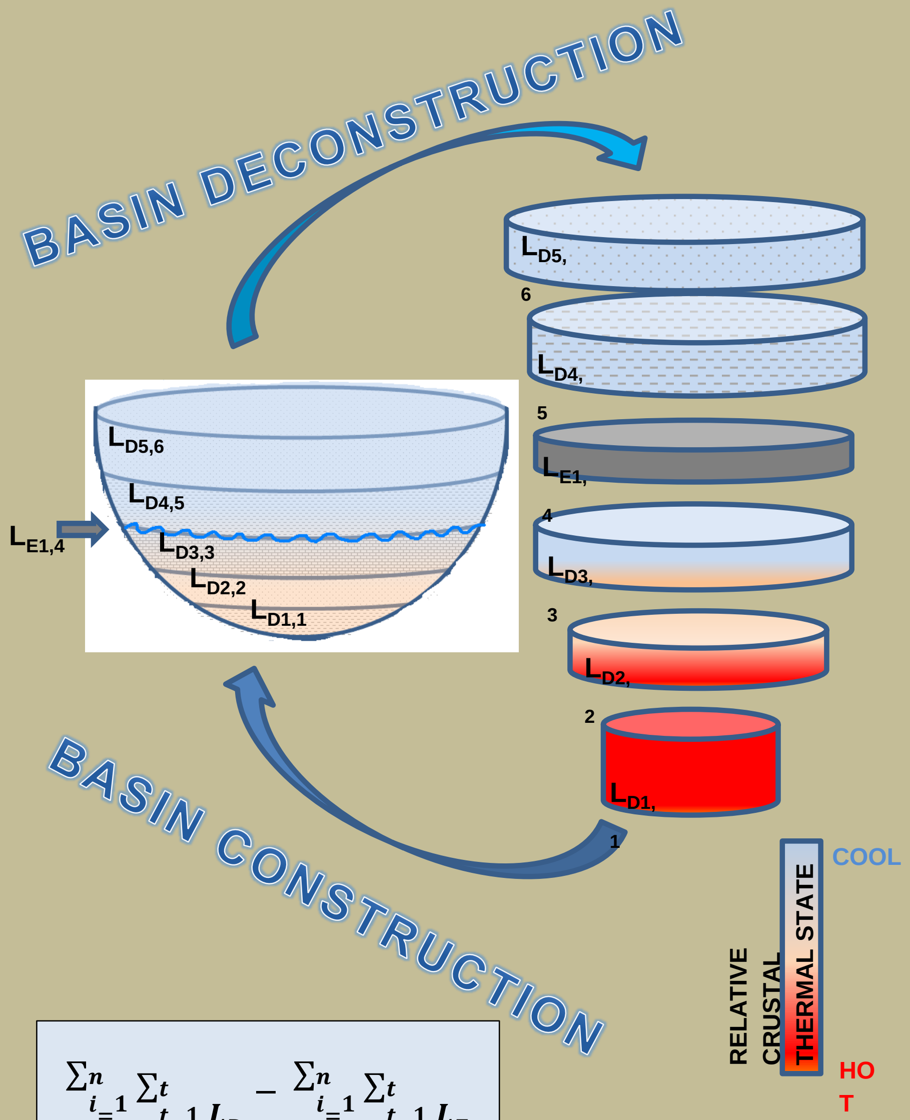
Like **books**, all **basins** have a beginning and an end, and in between the stories written in their pages differ. However, what is challenging in a geological context is that not all the pages are still there. Our question is this:



Regarding the two novels: **The Messinian Mediterranean Crisis** and **The Permian Delaware Basin Crisis**, what is the comparative anatomy of the two, how and why do they fill and drain, how does this affect other novels, that is how may this knowledge help our petroleum exploration efforts?

Problem Definition

To understand a basin, first we must deconstruct it, then reassembly it. In that way all those processes which affect a basin's evolution may be delineated, and importantly, in so doing inventory its petroleum systems, even those that no longer exist.



$$\sum_{i=1}^{n}\sum_{t=1}^{t} L_D - \sum_{i=1}^{n}\sum_{t=1}^{t} L_E$$

Why these two novels?

- Permian Basin of West Texas contains ~1% of world's oil reserves and is presently enjoying a surge in both conventional and especially unconventional exploration.
- The Mediterranean has a large variety of play types and is similarly experiencing a surge in exploration yielding dramatic new discoveries.
- A comparative anatomy of both basins can synergistically help delineate new fairways and allow a relook at bypassed pay in old ones.

Strategy

I. Prologue (Problem Definition)

II. Literary Criticism (Comparative Anatomy)

A. **“The Messinian Mediterranean Crisis”**

i. The Plot (Basin Deconstruction)

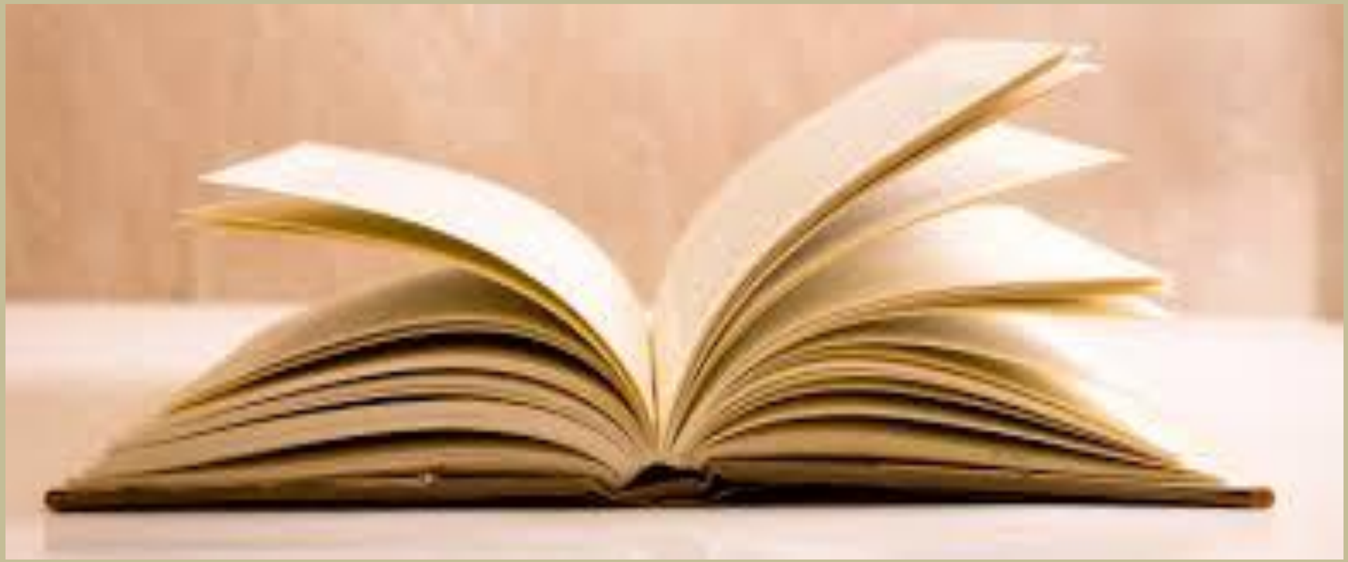
ii. The Setting (Tectonics, Paleogeography, Eustatic Sea-Level)

ii. Action and Time line (Tectonics, Climate, Geology)

iii. Conclusion (Effects on Petroleum System)

B. **“The Permian Delaware Crisis”**

III. Epilogue



The Messinian Mediterranean Crisis

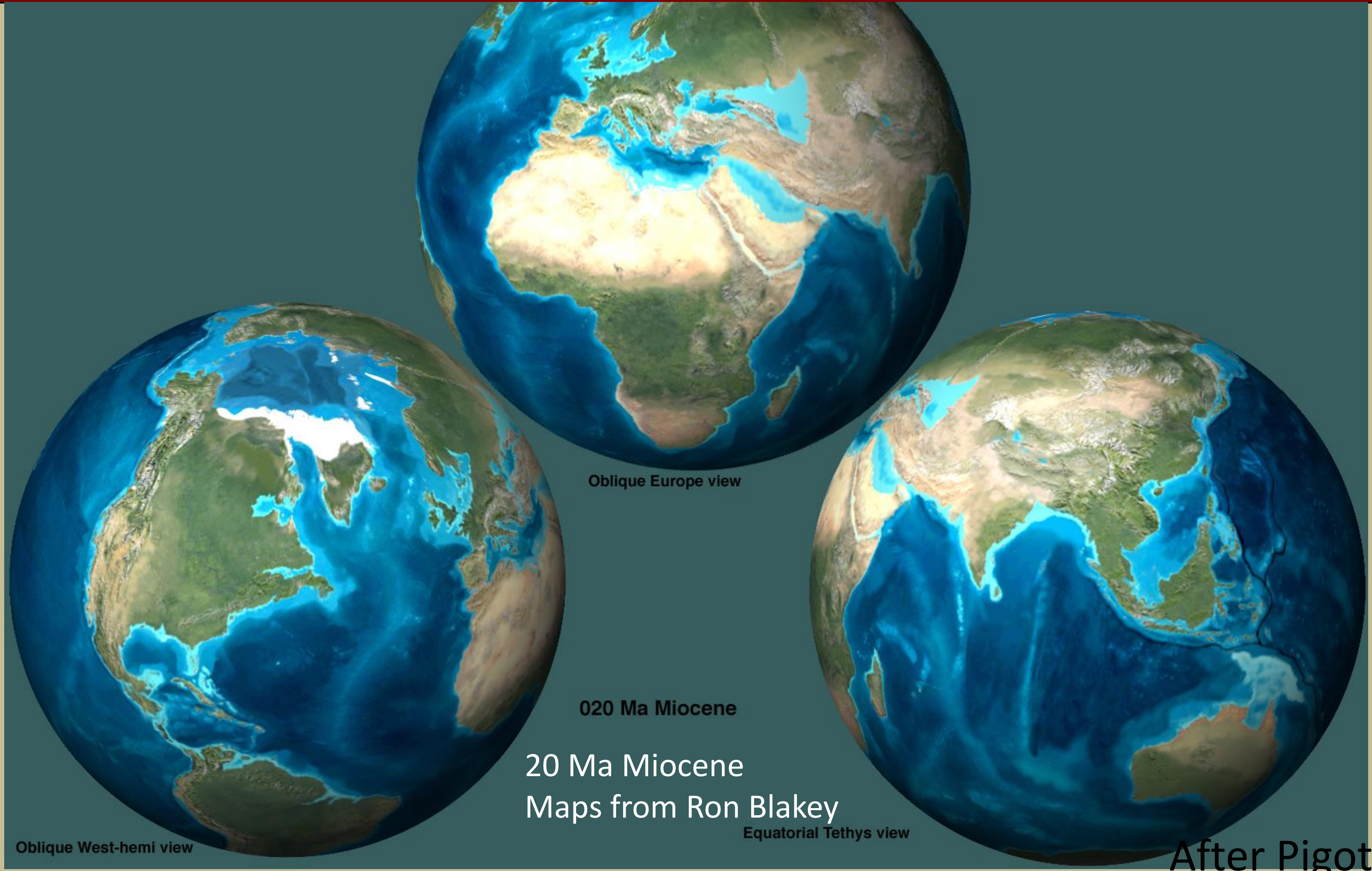
Messinian Mediterranean Crisis

The Plot

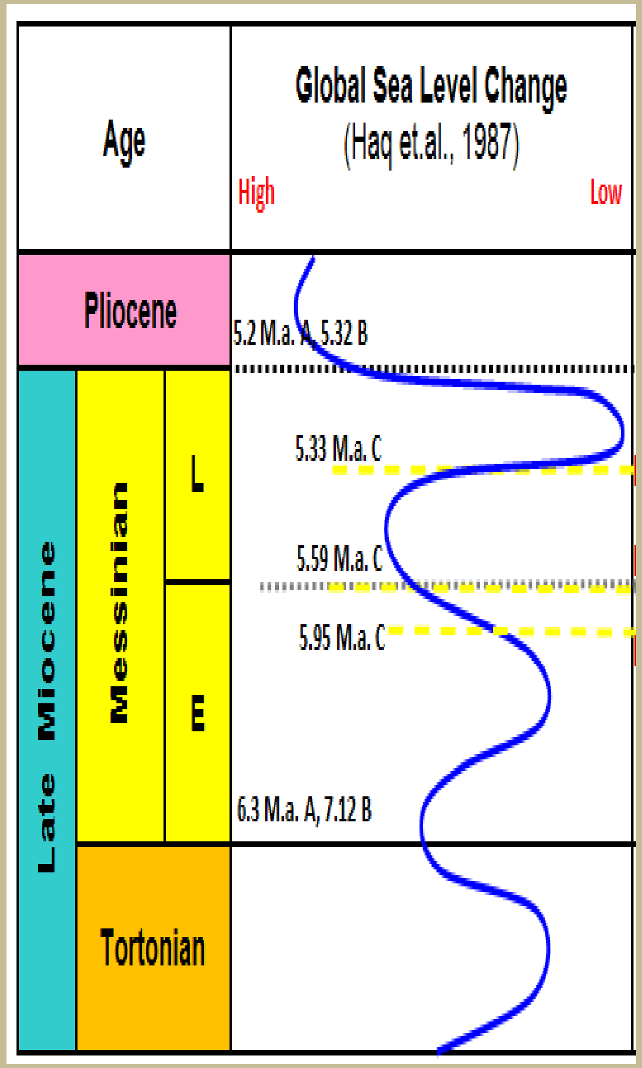
In brief the plot goes like this:

1. During the Late Miocene the Strait of Gibraltar closed off and the Mediterranean Sea, separated from the Atlantic on the West, goes into desiccation.
2. For the next 630 thousand years, environments change drastically, river cut canyons, both deep water and shallow water evaporites result, and those interior basins 3-5 km below sea level exceed 70 deg C, culminating in thick evaporite deposits.
3. The Atlantic from time to time spills over into the basin, but suddenly, at the beginning of the Pliocene, the Straits open, the Atlantic rushes in as a deluge a 1000 greater than the Amazon, and the basin fills once again.

Paleogeography/Sea Level*



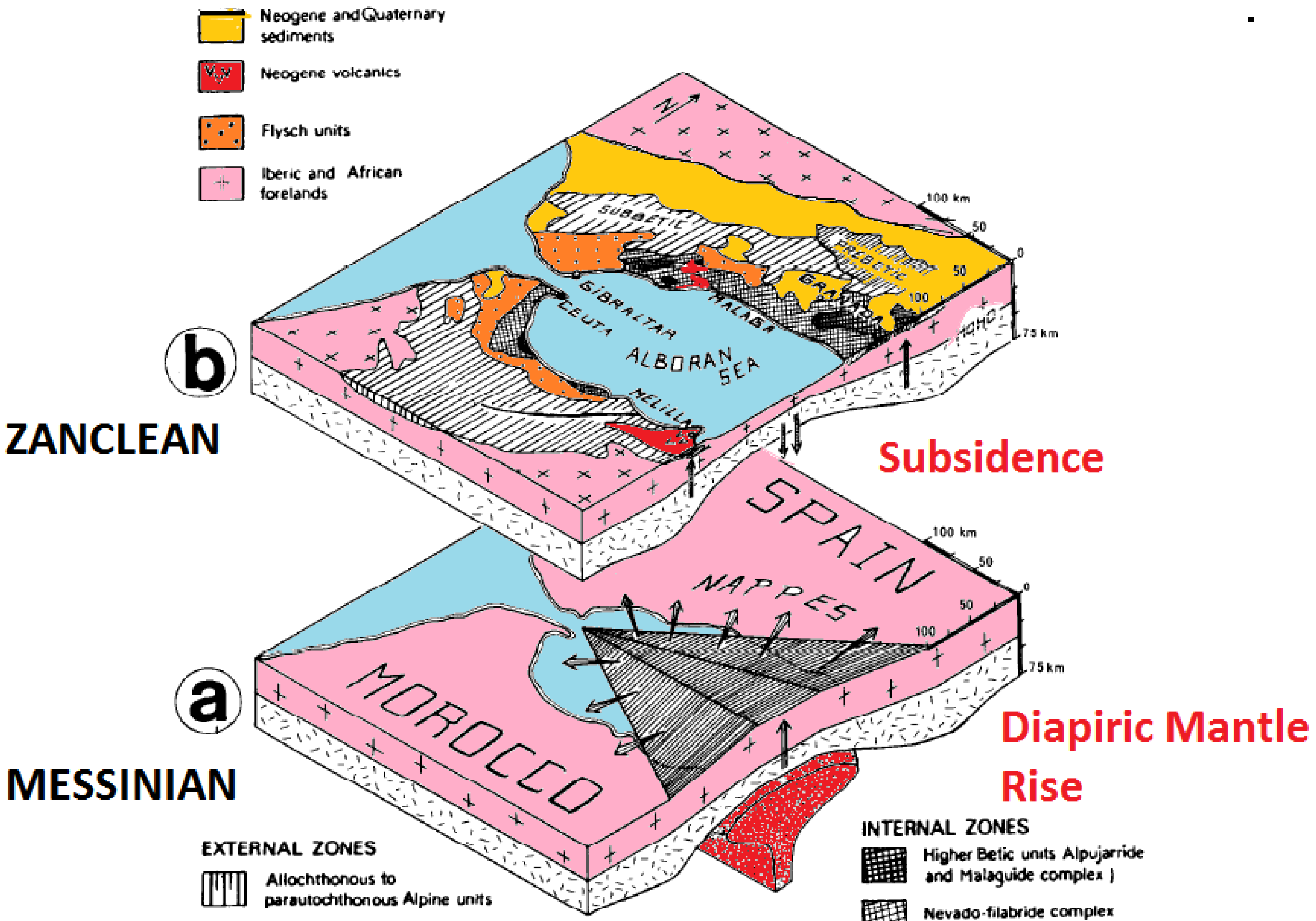
20 Ma Miocene
Maps from Ron Blakey



After Pigott and Abdel-Fattah, 2014

Tectonics

Western Mediterranean Tectonic Closure



Adapted from Weijermars, 1987.

Mediterranean begins to dry

Estimates of Mediterranean drawdown exceeding 800m but leaving deep water evaporites up to 2.5 km in thickness.

Mediterranean interior heats up

Estimates of interior basin temperatures exceed 60 deg C. Great biologic changes ensued.

Rivers deeply incise, well evidence

Closing off of Mediterranean at Gibraltar Strait led to desiccation and downcutting of rivers, e.g. Nile

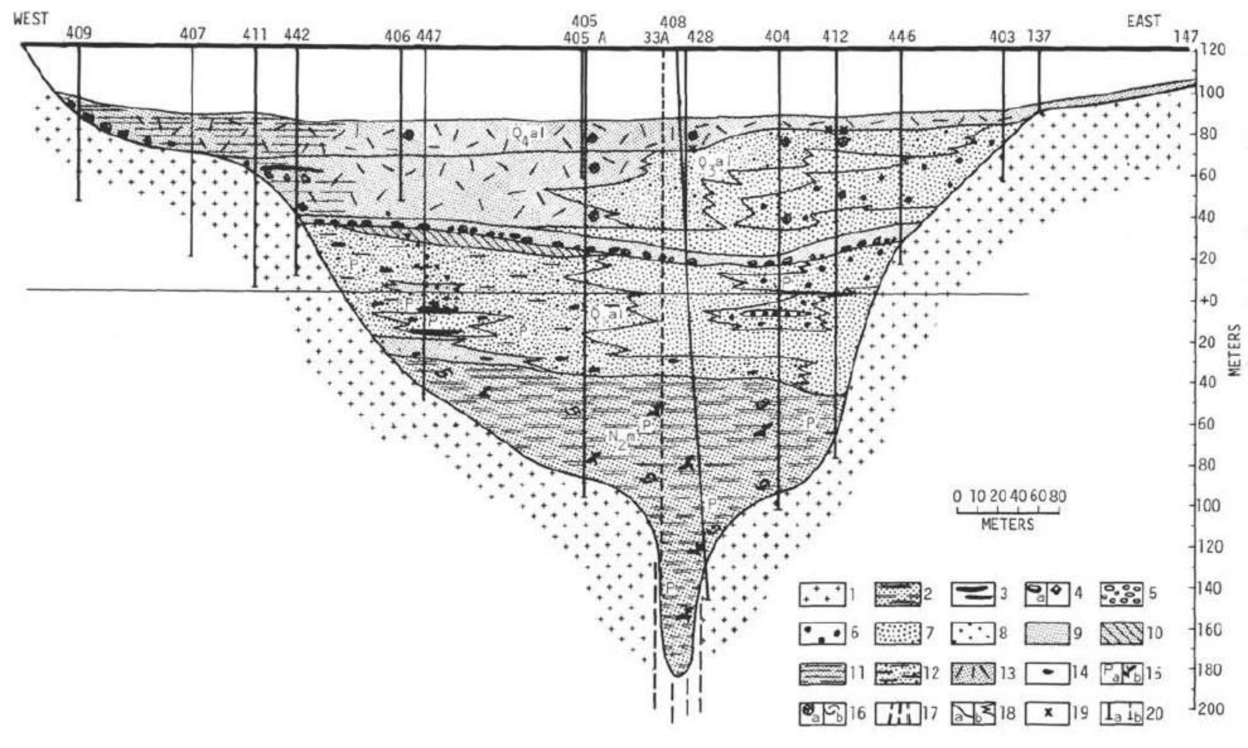
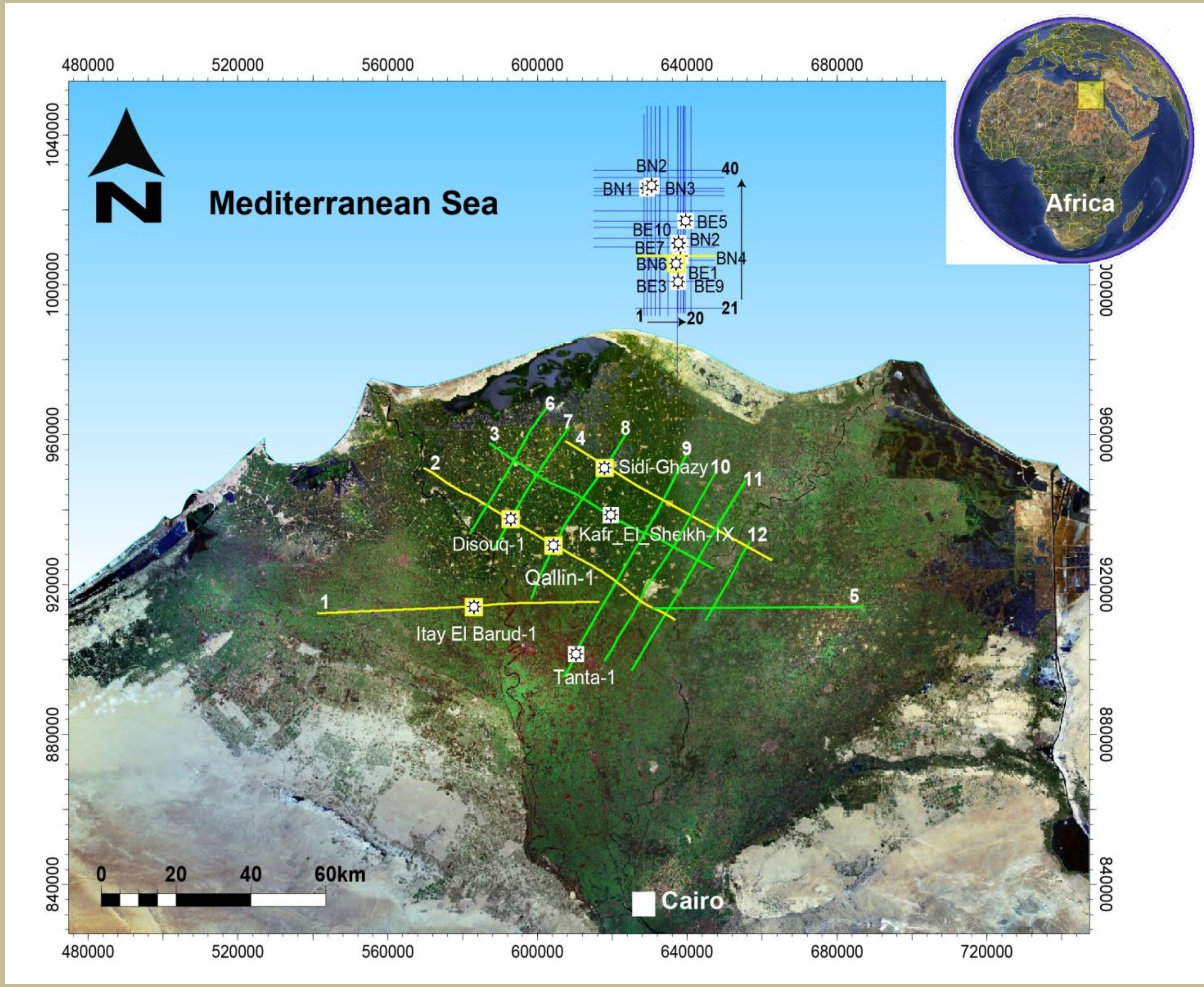


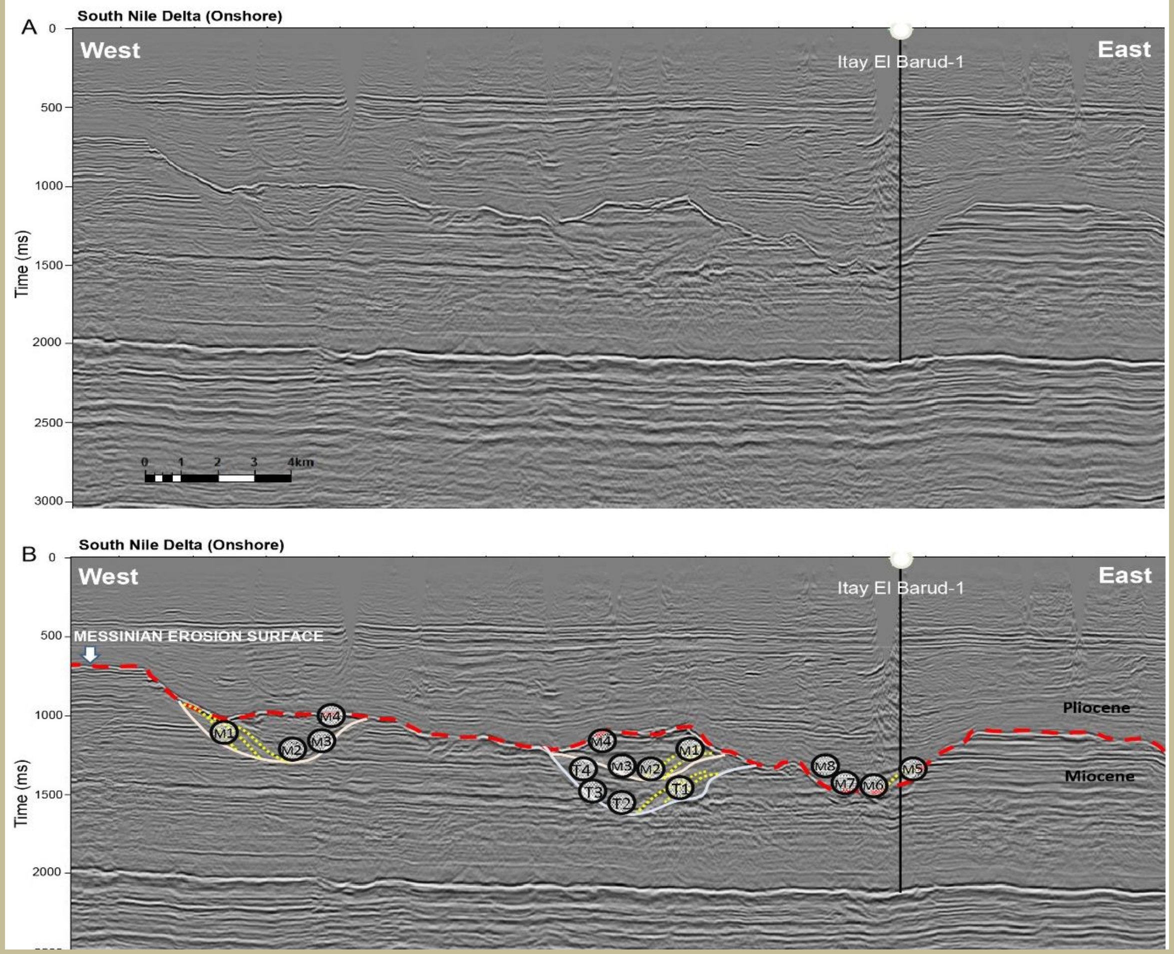
Figure 1. *Geological cross-section from boreholes of the Upper Nile Valley south of the Aswan Dam. Legend: (1) rocks of crystalline basement (gneiss and granite); (2) clay with layers of sand and sandy loam; (3) clay lenses in sand; (4a) boulders; (4b) blocks and fragments; (5) pebbles; (6) gravel; (7-13) sands; (7) coarse sand; (8) medium sand; (9) fine sand; (10) sand with thin layers of soil and remains of roots; (11) clayey sand; (12) sand with interbedded clay and loam;*

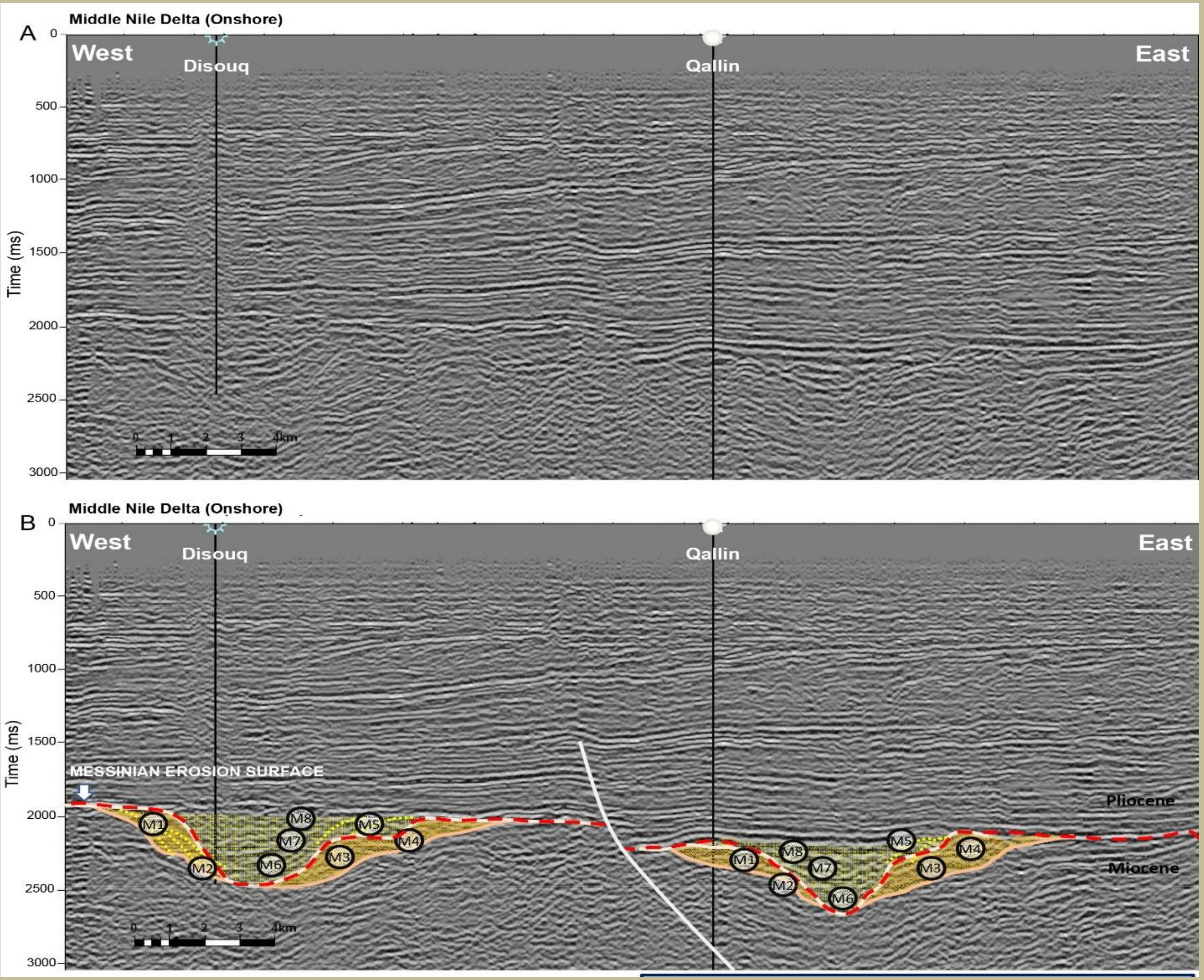
Rivers deeply incise, seismic evidence

Dramatically revealed in Egyptian seismic



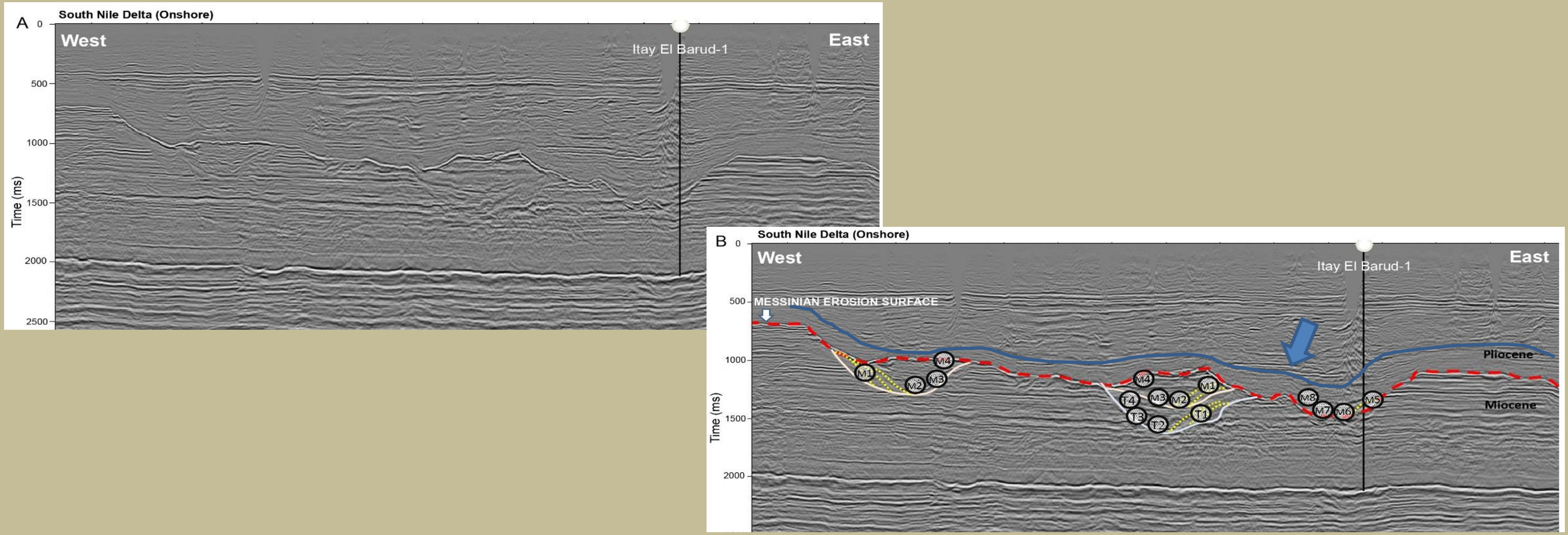
Rivers deeply incise





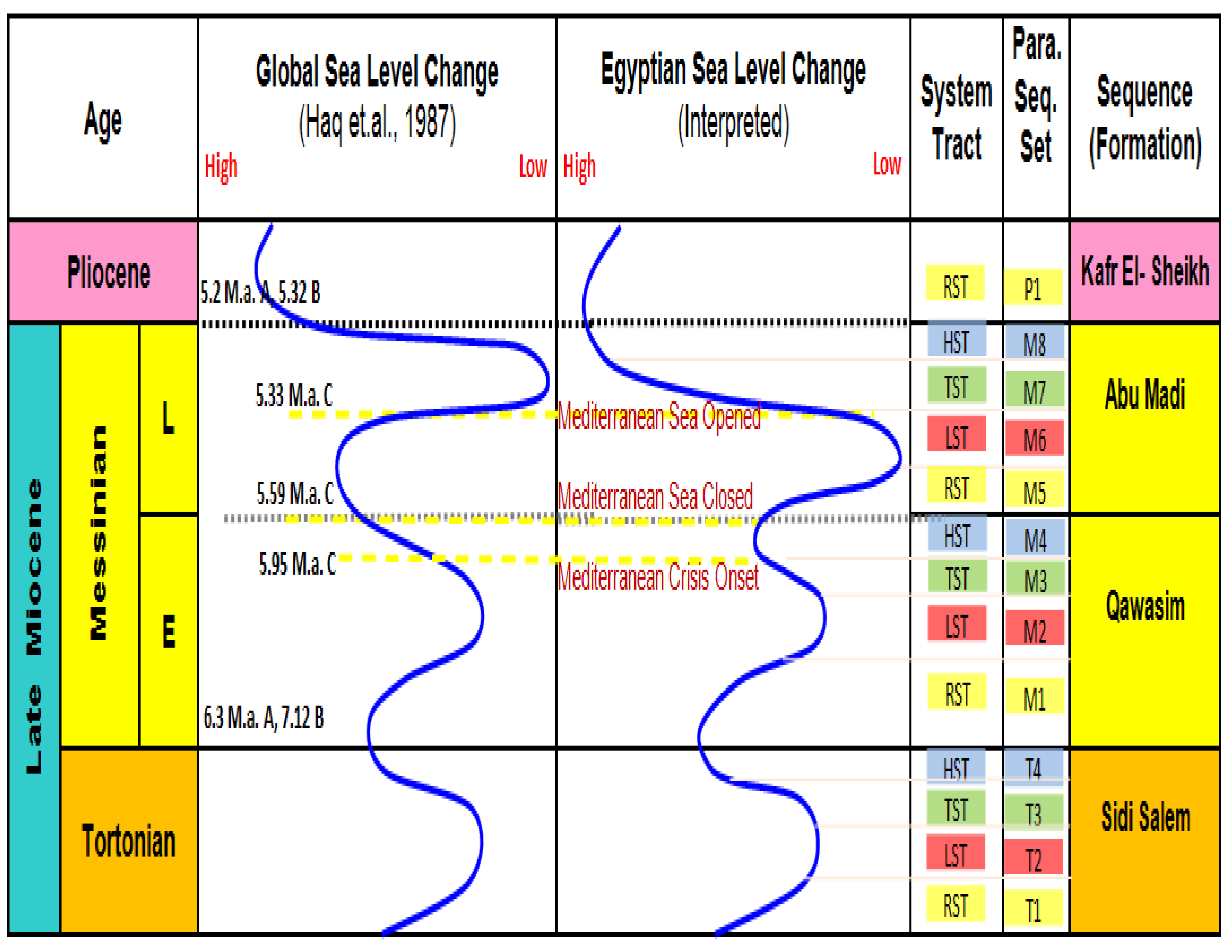
But then, something strange happens

A huge substantial thickness of onlapping, transgressing shale of retrograding Nile delta occurs capping these channel sands within the incised valleys…regard again (indicated by the blue arrow):



Sea Level*

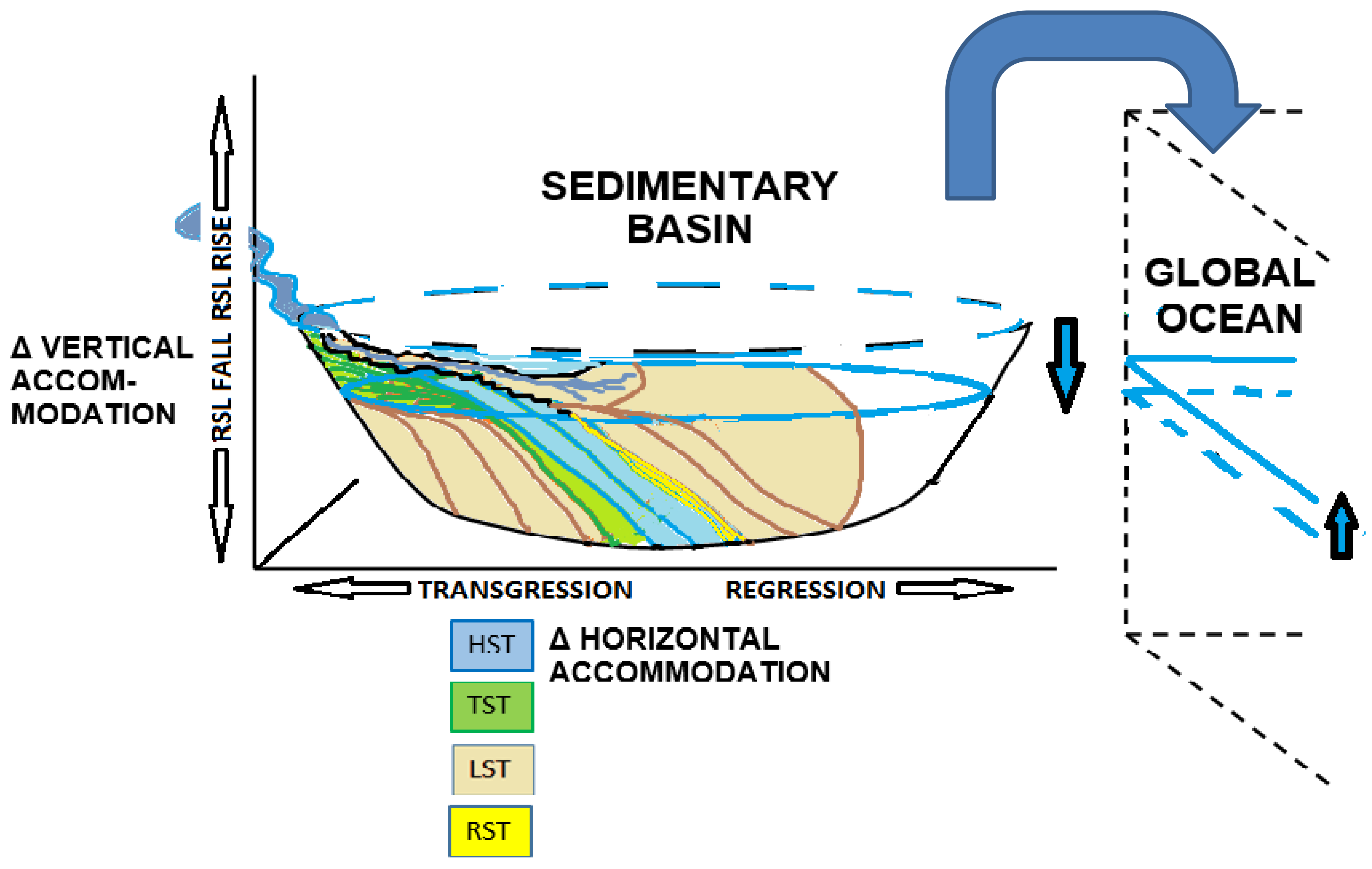
Reconstructing the sea level using high resolution sequence stratigraphy on wells provides not only timing, but also a Mediterranean sea level curve which is out of phase with the Global Curve…**Why?**



From Pigott and Abdel-Fattah, 2014

The Sea Level Disjunction

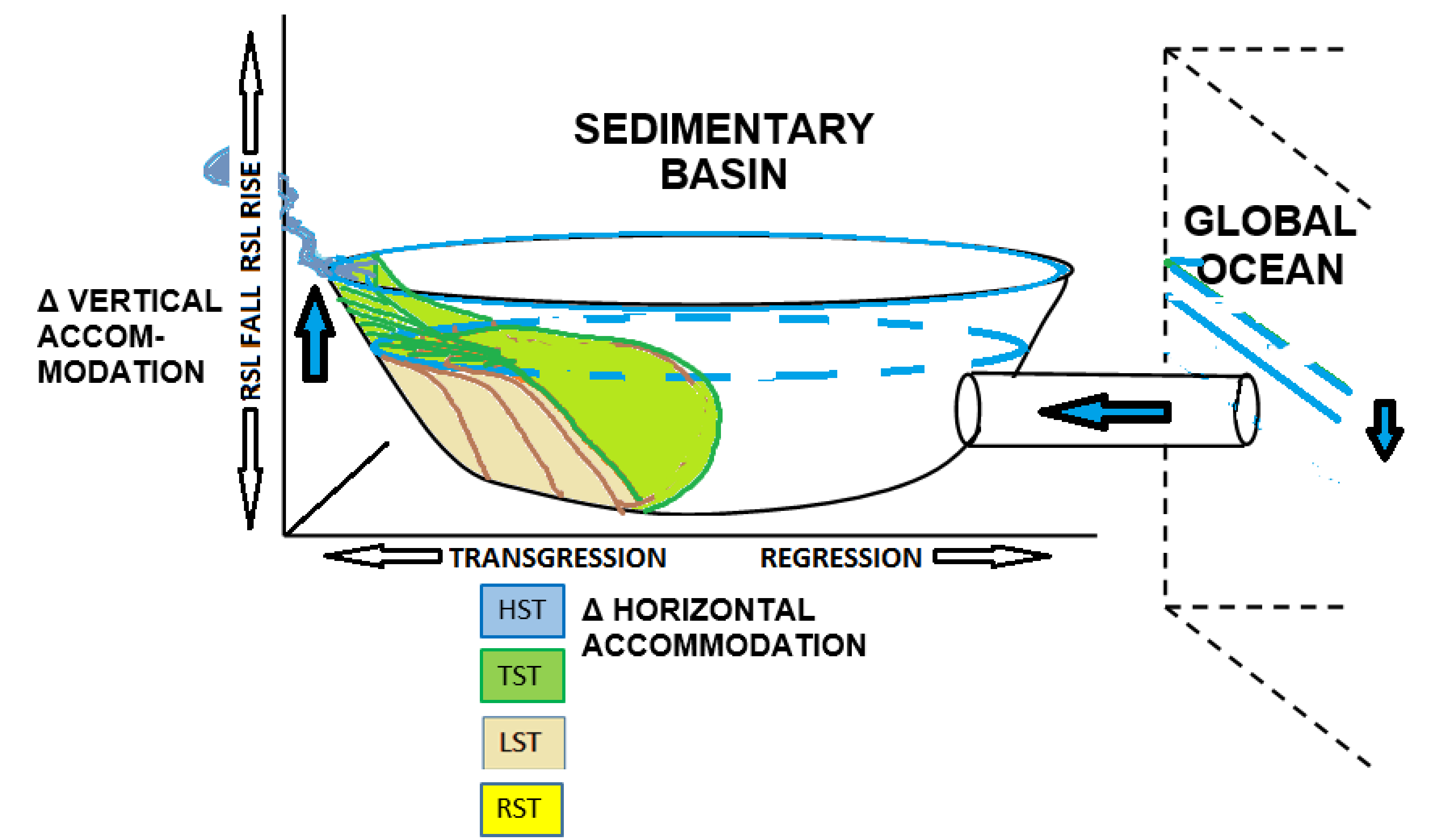
Water mass transfer, e.g. Mediterranean evaporates, global ocean rises



Adapted from Pigott and Bradley, 2014

The Sea Level Disjunction

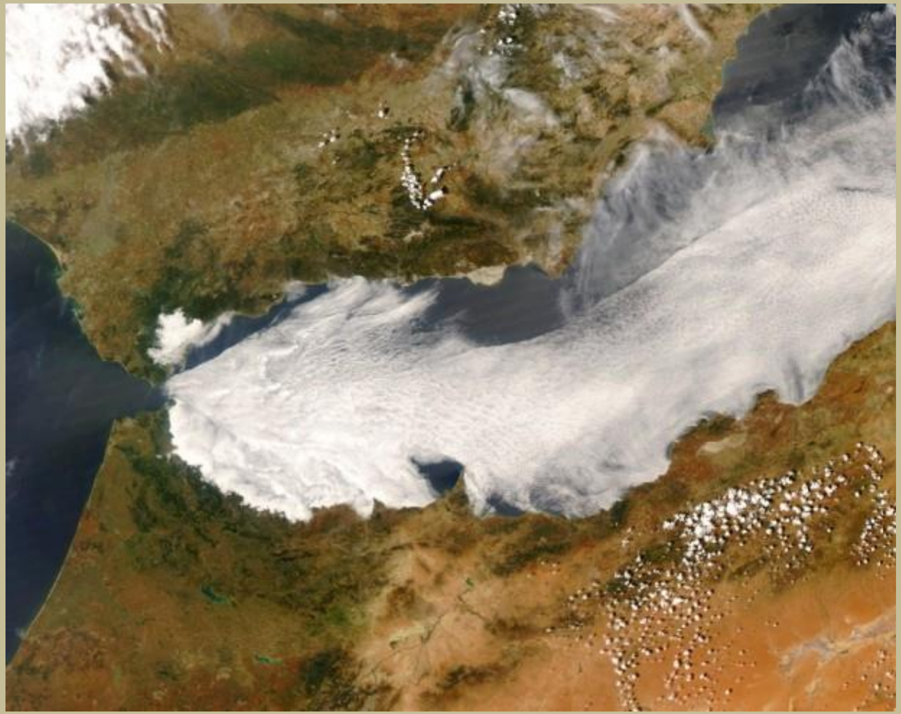
Water mass transfer, e.g. sudden opening to Atlantic, Mediterranean fills, TST results



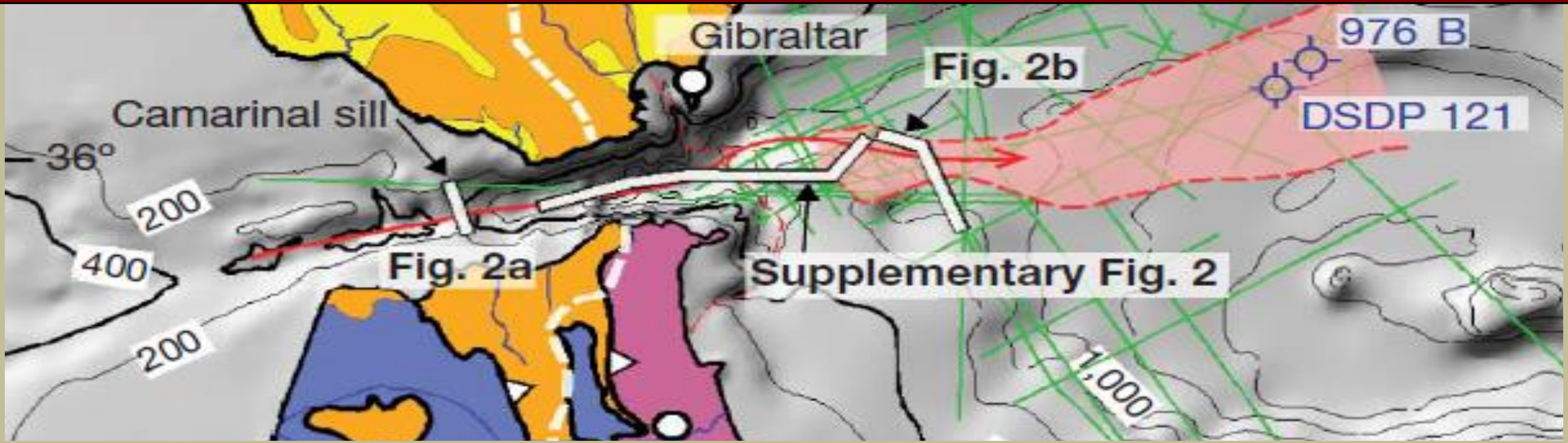
Adapted from Pigott and Bradley, 2014

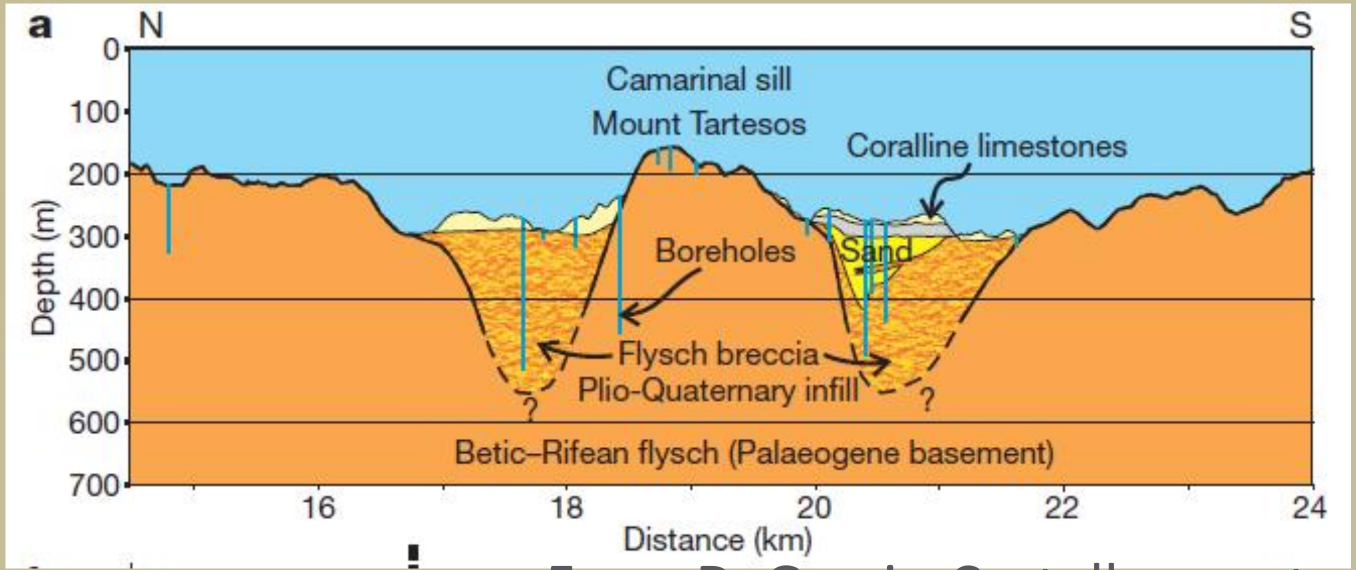
Zanclean Flood

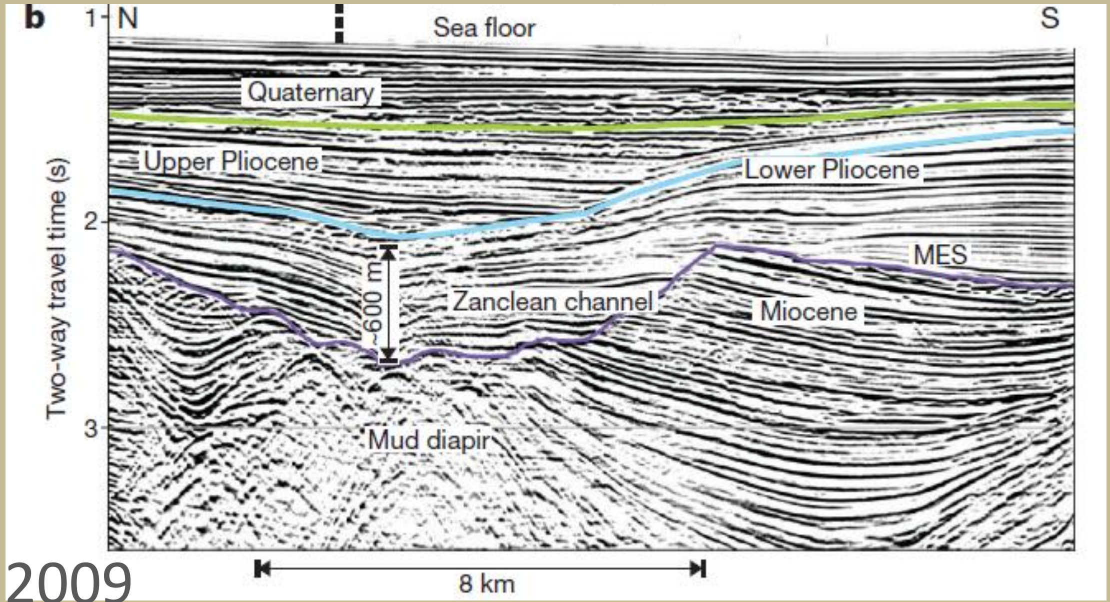
There was not only closure, but a re-opening of the Gibraltar Strait providing an inflow rate estimated to exceed 1000X that of the Amazon (Garcia-Castellanos, 2009) in less than two years!



Zanclean Flood Torrent Incision





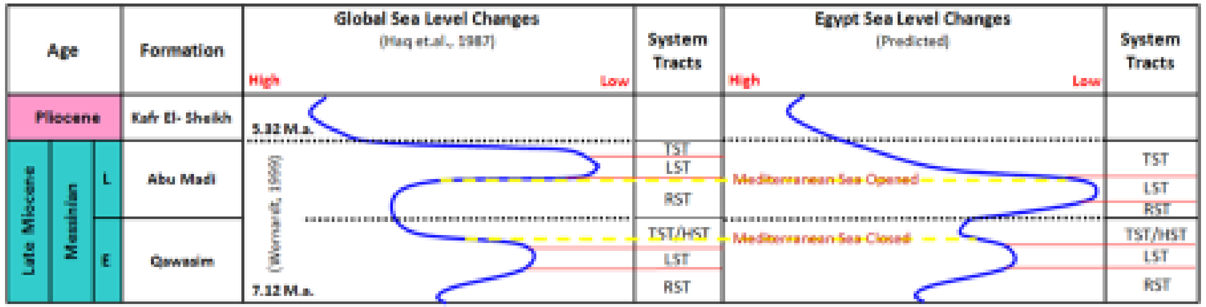


From D. Garcia-Castellanos et al., 2009

Antithetic SL Curves

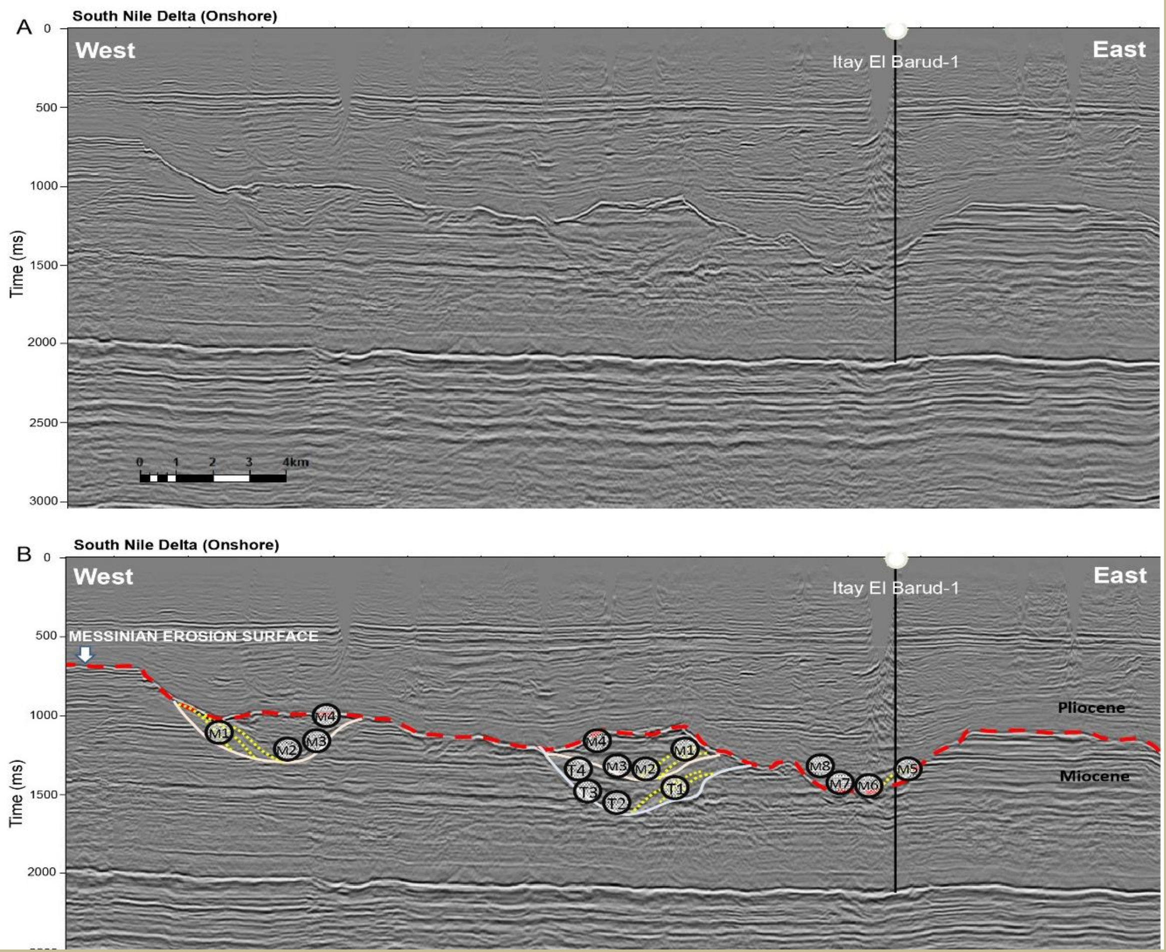
Thus the Egyptian Sea Level curve reveals the transfer of billions of liters of water into the World Oceans, and later the transfer back resulting in antithetic SL curves

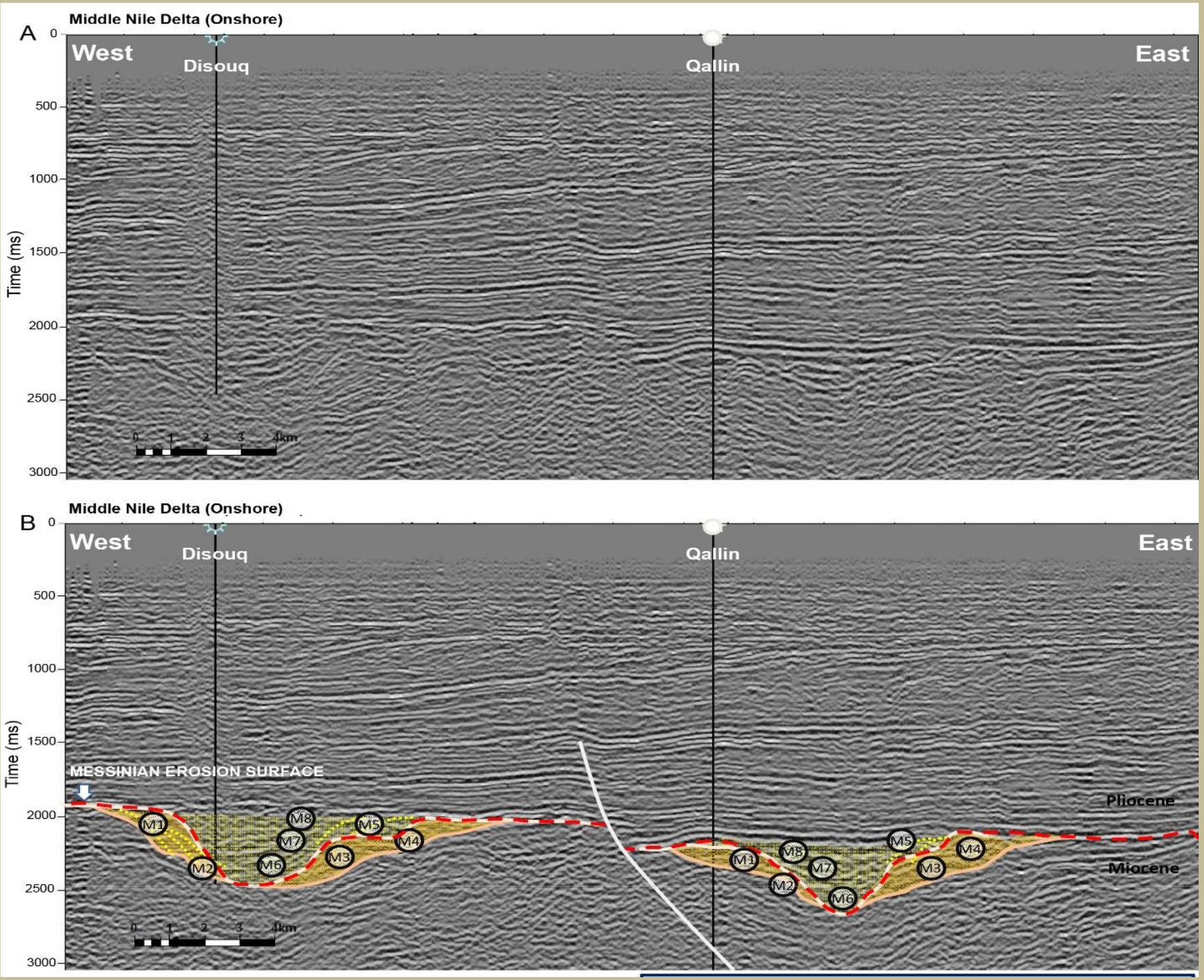
Sea Level Changes



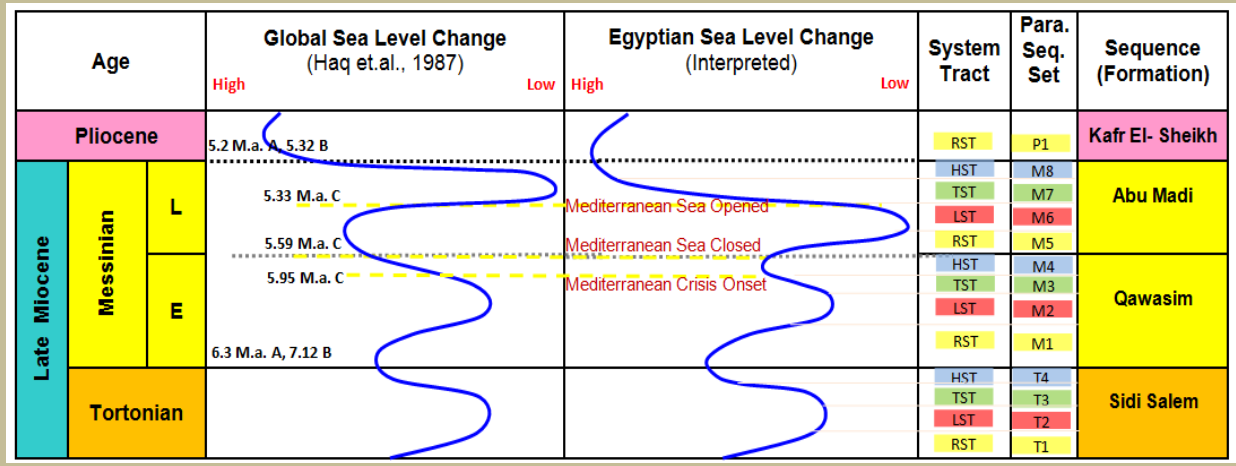
Sea Level Changes in the Messinian age (modified after Haq et. al. 1987 and Wornardt, 1999)

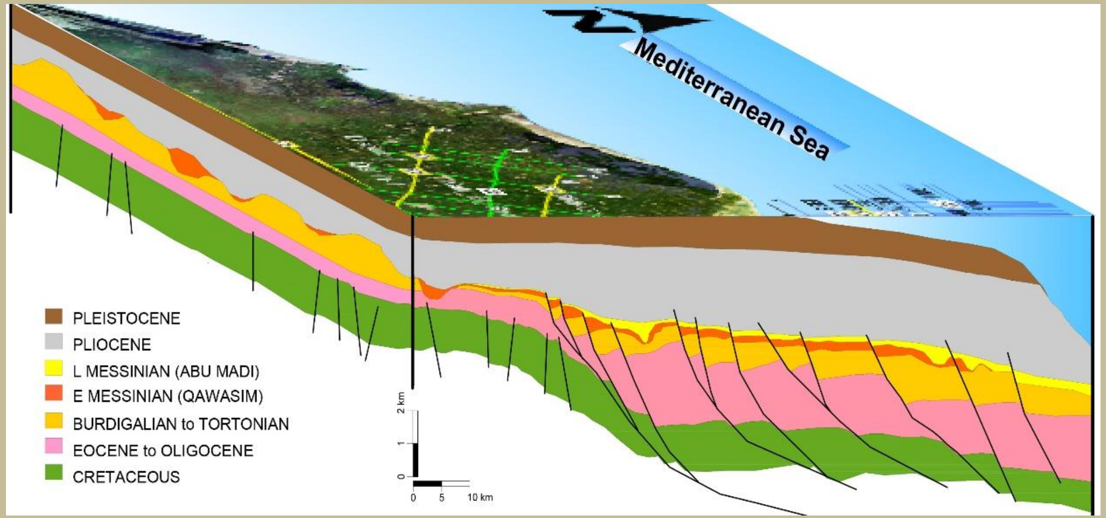
One Petroleum System Implication: the RST

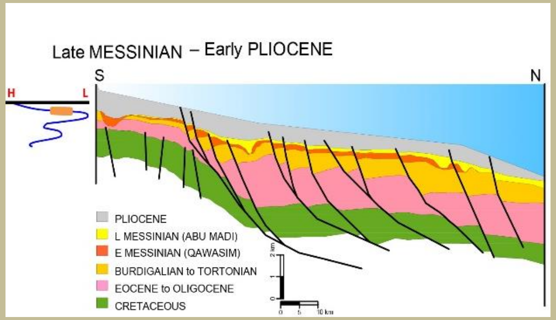


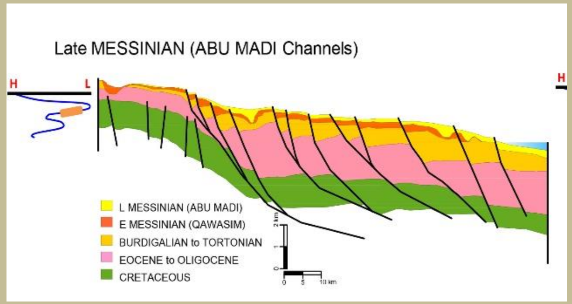


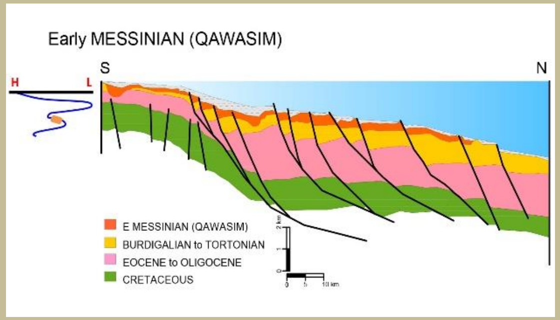
Messinian subcycles

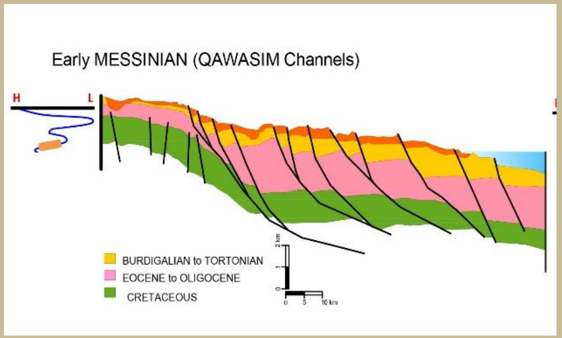








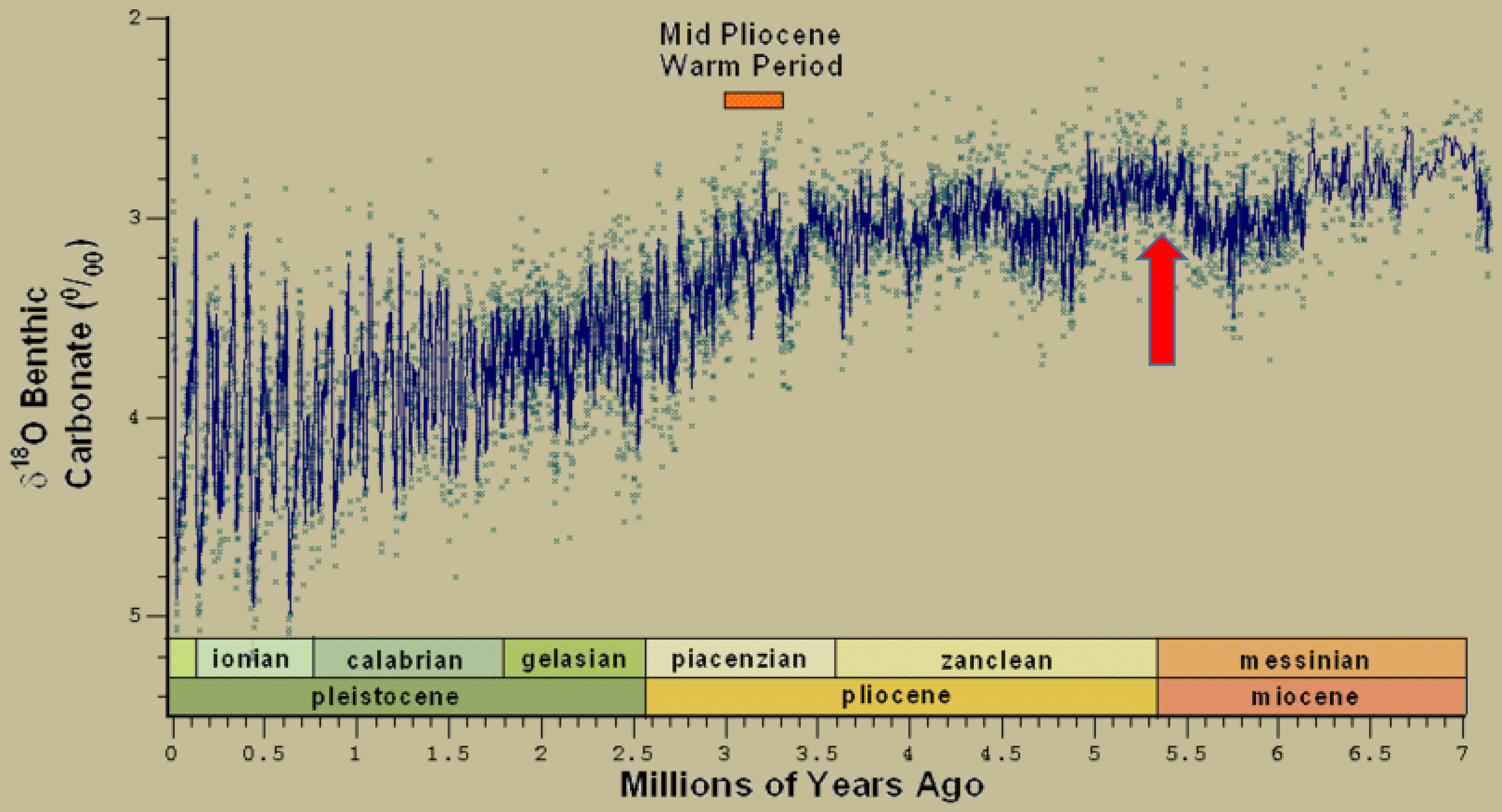




The transgression leads to encapsulated RST reservoirs

Methane release…global warming?

With Zanclean Flood and sudden drop in the global sea level, could this rapid bathymetric pressure drop cause methane cathrate gas release? Isotopes do show a spike in global temperatures…



Next volume…

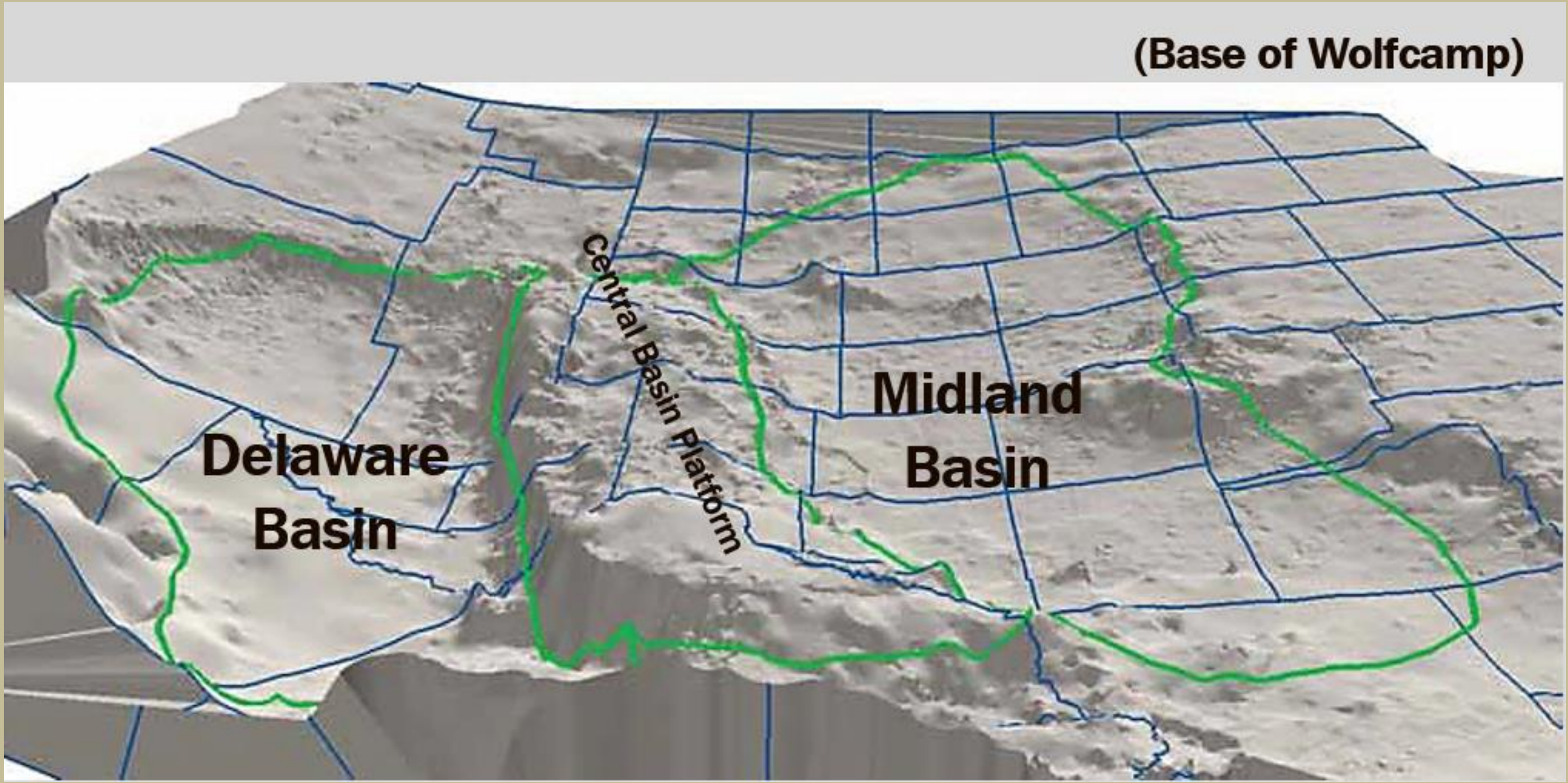
In our continuing Literary Criticism, let us now look at the next book…entitled

The Permian (Ochoan) Delaware Basin Crisis

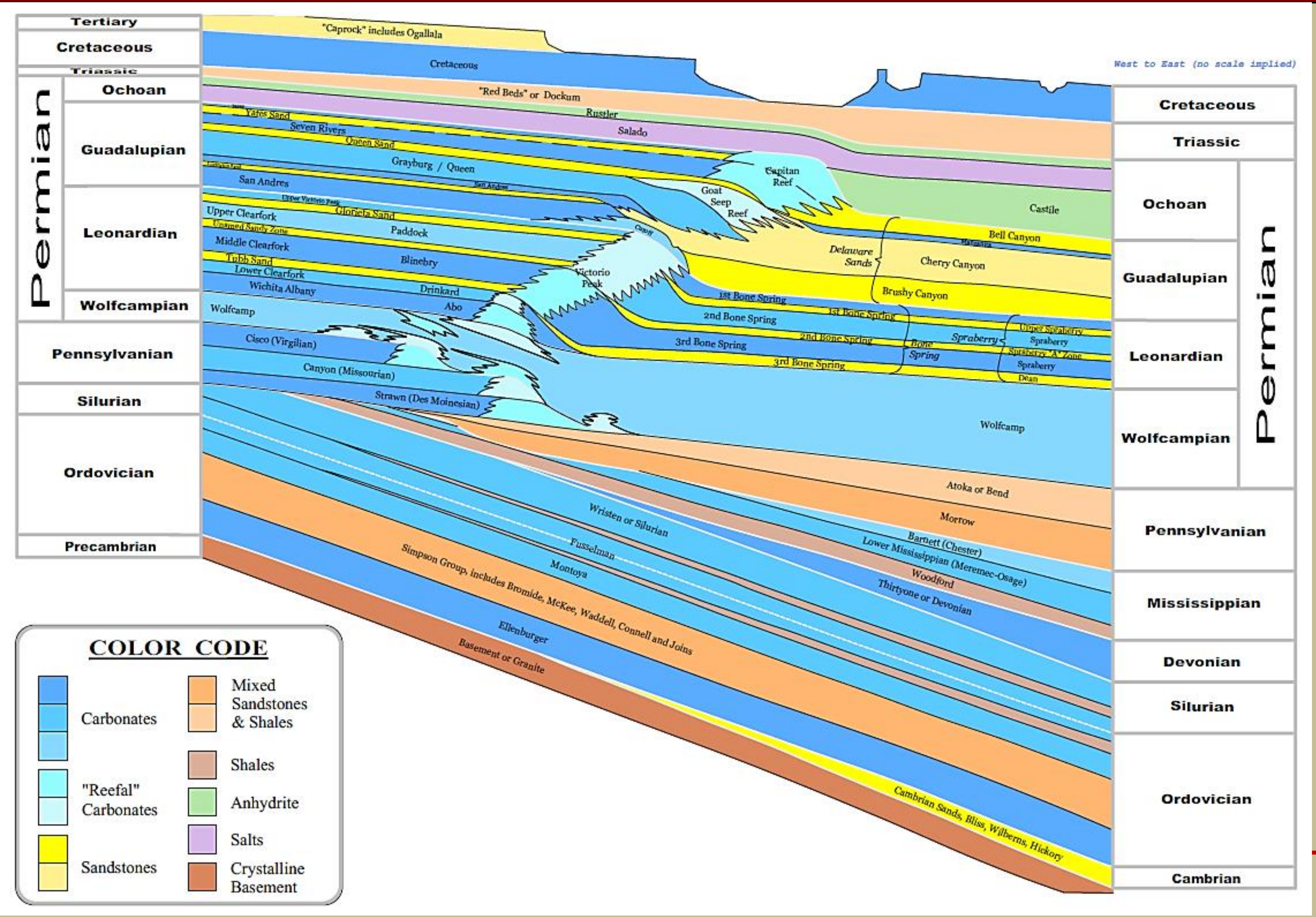
In brief, the plot goes like this:

1. During the Late Permian (Ochoan) the Hovie Channel closed off isolating the Delaware Basin from the Panthalassia Ocean to the West, and the restricted basin underwent intense cyclical evaporation.
2. Shallow water and thick deep water evaporites (Castille) accumulate.
3. The restriction is followed by a mild marine incursion, then emersion until the present day.

Setting

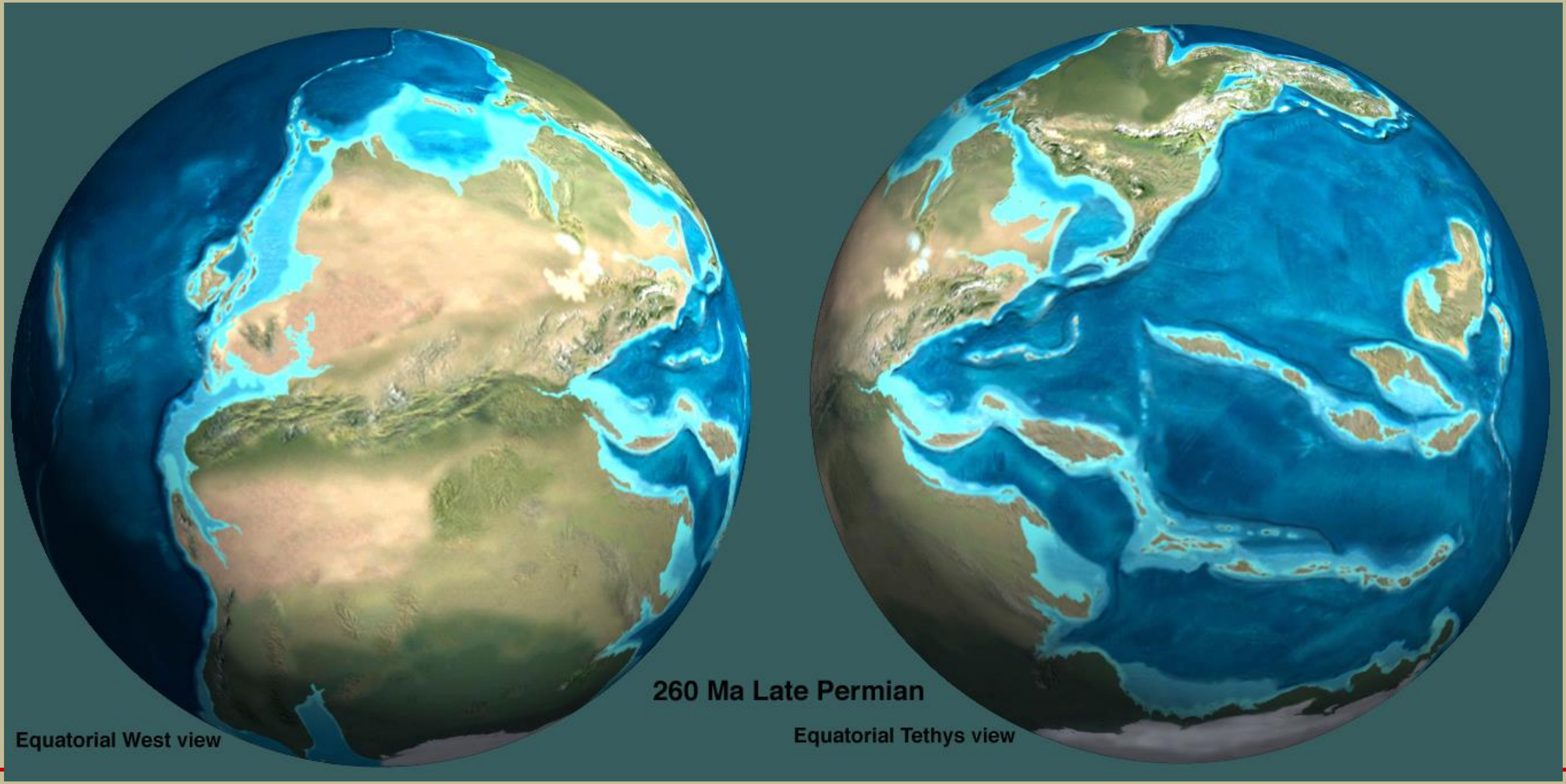

(Base of Wolfcamp)
Central Basin Platform
Midland Basin
Delaware Basin

Stratigraphy

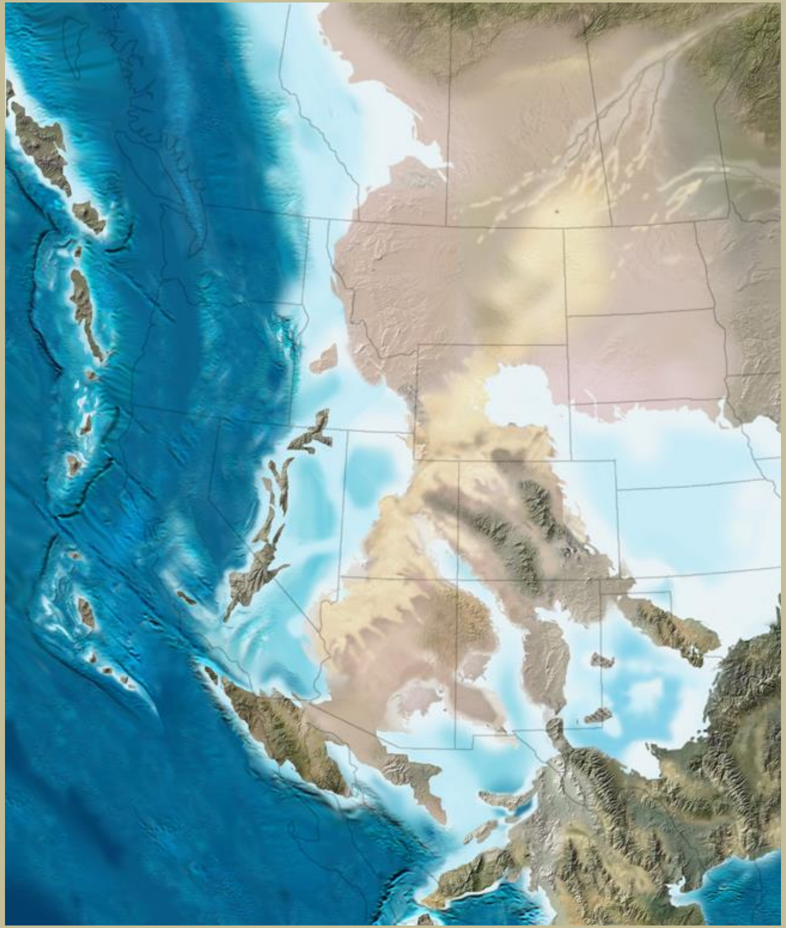


Paleogeography, Global

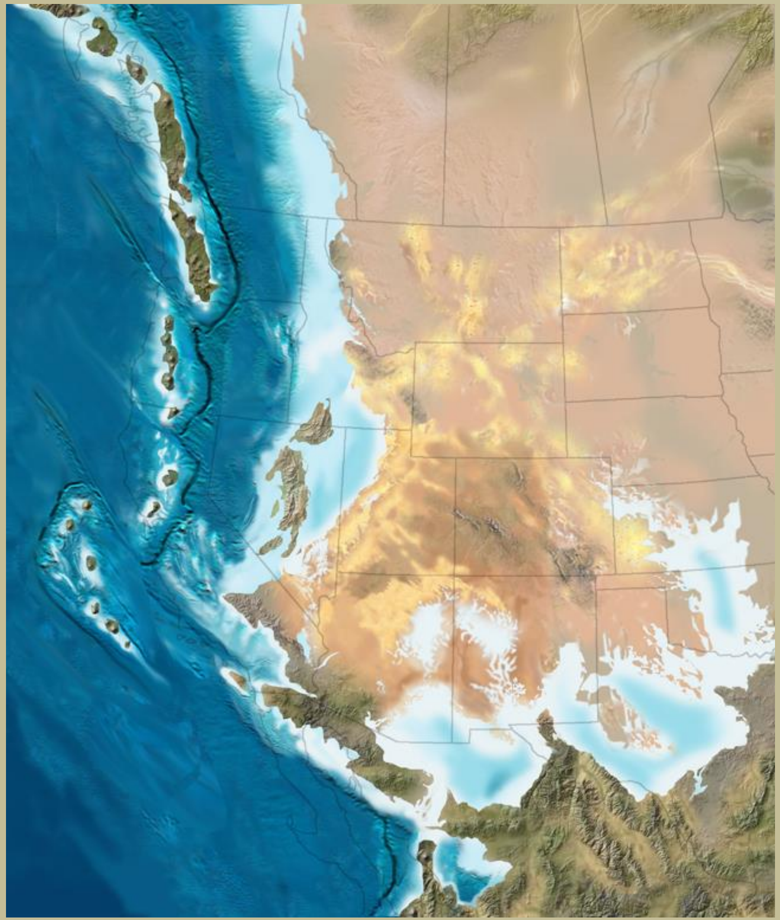
A time of a super-continent, Pangea



Paleogeography, Delaware Basin



300 Ma Carboniferous



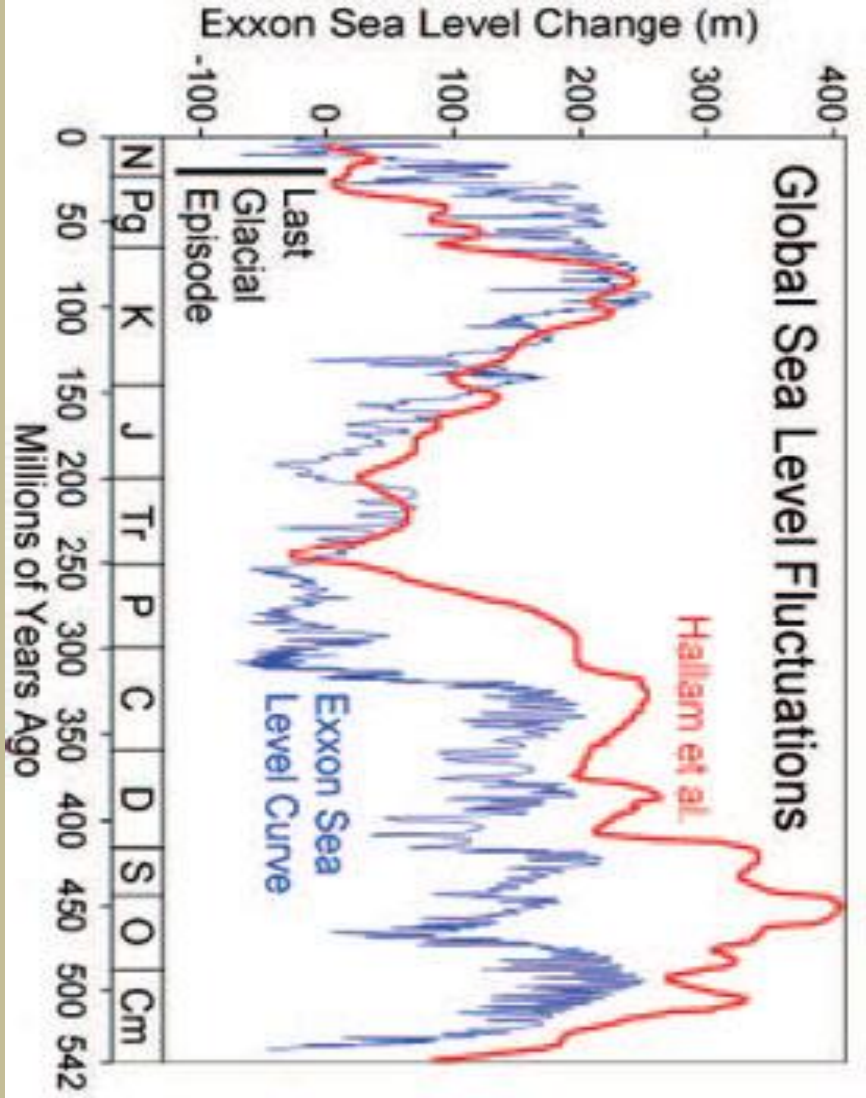
280 Ma Permian

245 Early Triassic

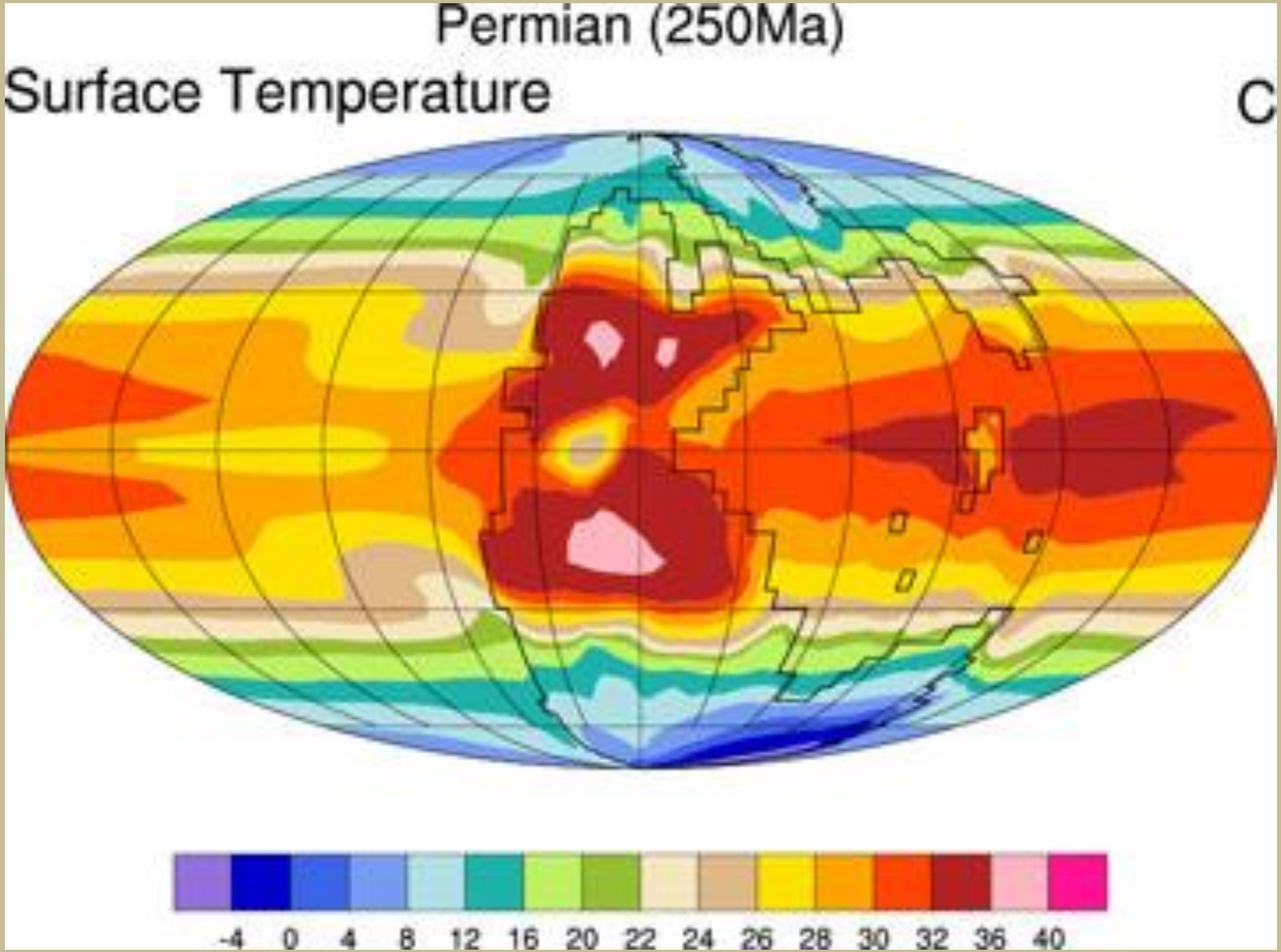
Maps from Ron Blakey

Eustatic Sea Level

It was a time of one of the lowest global sea levels, and another precipitous fall at the Permo (Ochoan)-Triassic Boundary, the "Ochoan Crisis".



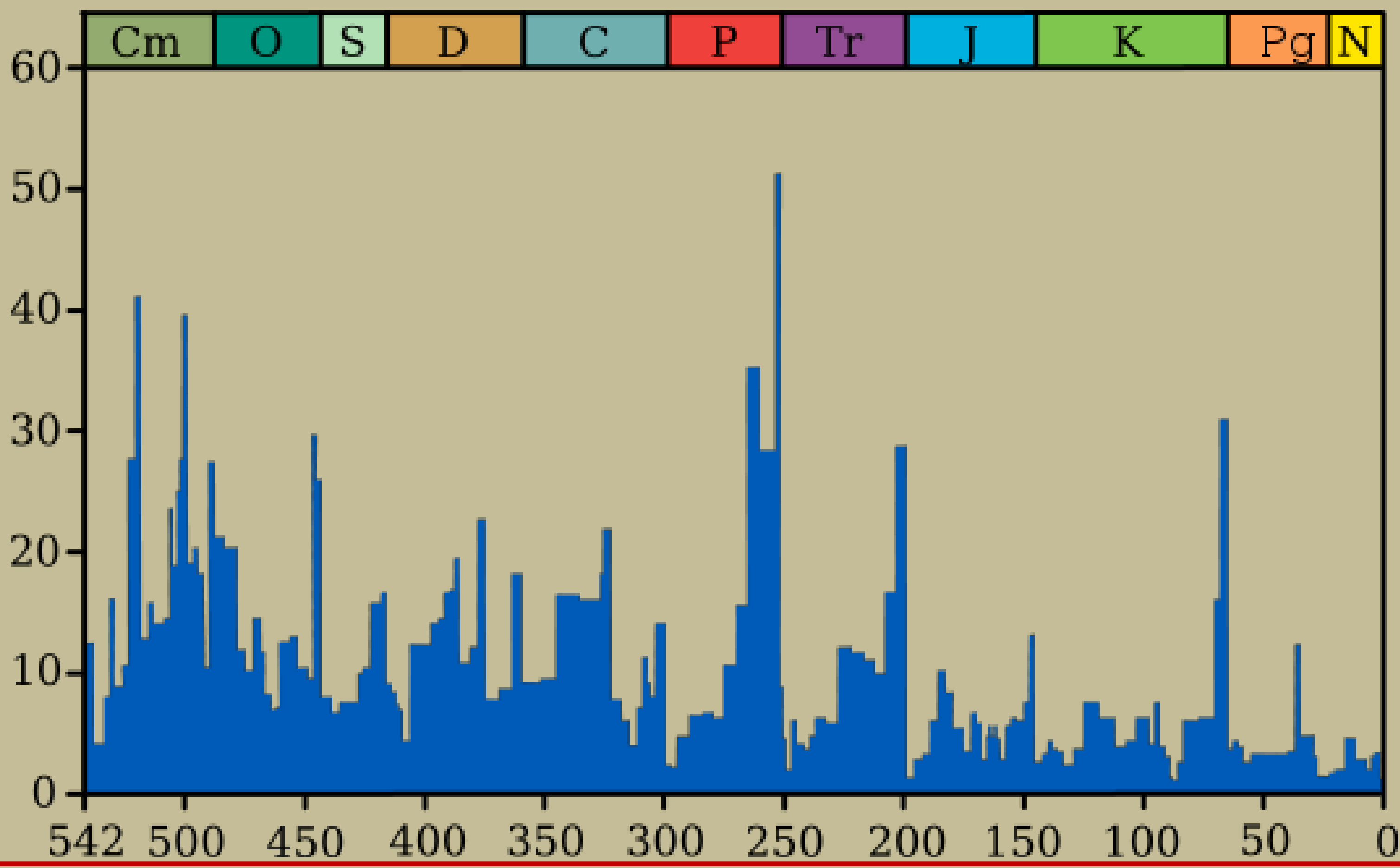
A time of elevated temperatures



Late Permian Temperatures Western Hemisphere (Jeff Kehl, 2005); Delaware Basin vicinity mean exceeding 36 deg C.

A time of great extinctions

Some workers estimate that 90% of marine and 70% of terrestrial species died out at the Permo (Ochoan)-
Triassic boundary.



Extinction Intensity
After Rohde & Muller (2005)

The plot thickens…

As Sea Level continued to fall globally, with accompanying Mesozoic Pangea break-up exacerbating localized uplifts owing to volcanics and incipient rifting nuclei, globally elevated temperatures, with borders to inlets closed vast aqueous evaporite deposition occurred in numerous basins around the world, and especially, in the Delaware.

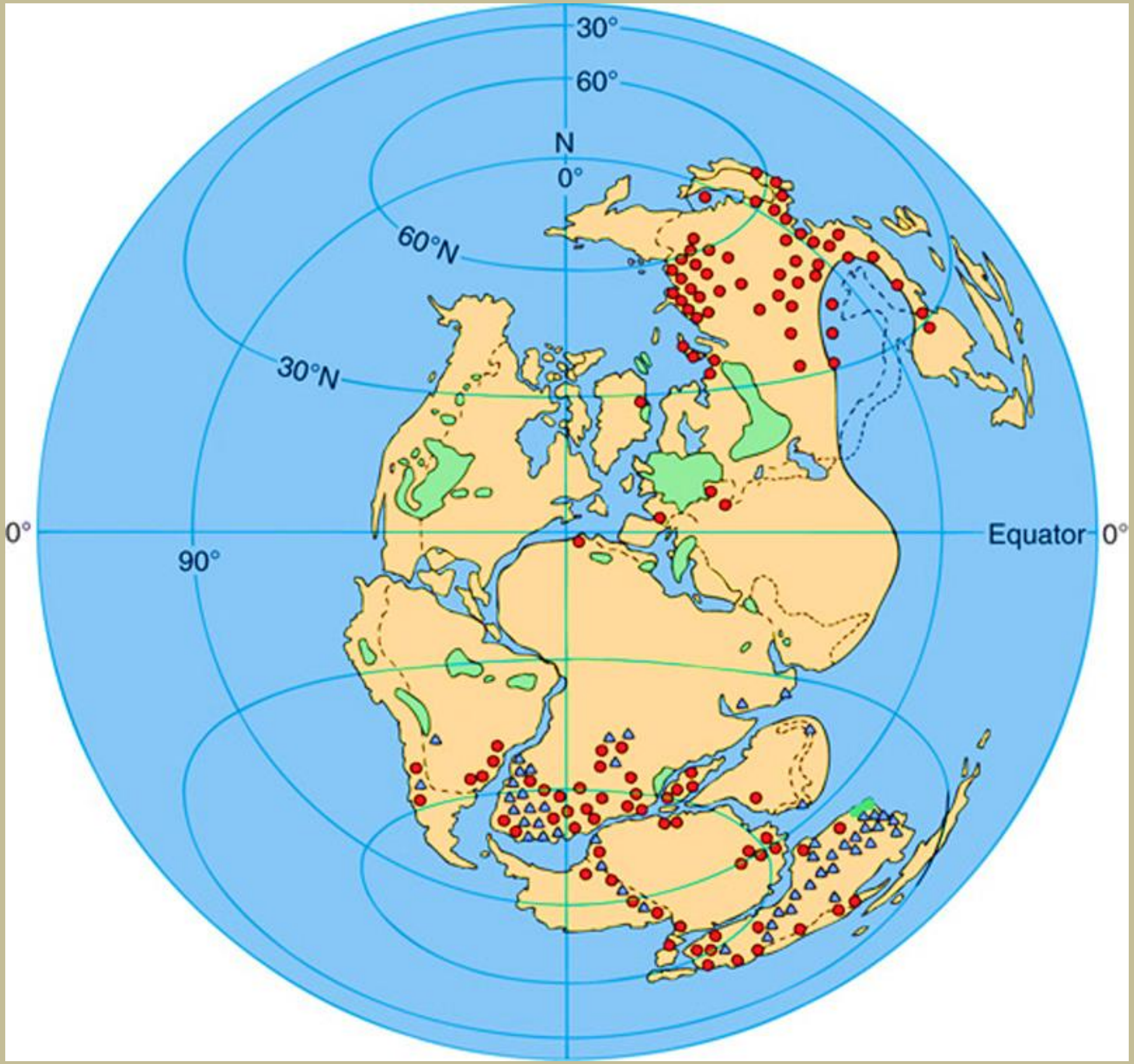
Paleogeography

Red circles are coal deposits (humid climates during interglacial periods, possibly associated with glacial meltwaters).

Blue triangles are glacial tillites.

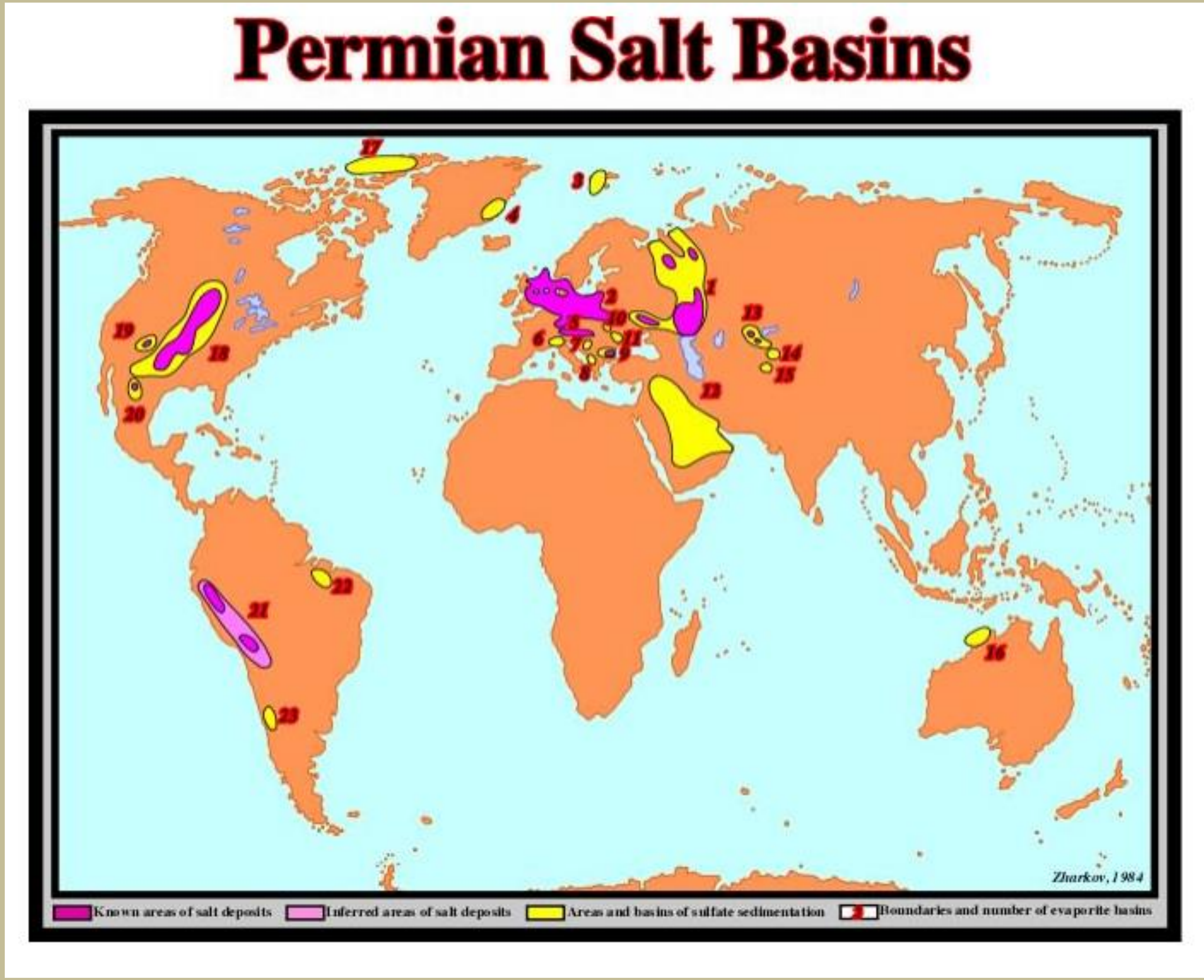
Irregular green areas are evaporites (arid climates).

After Levin (2005)



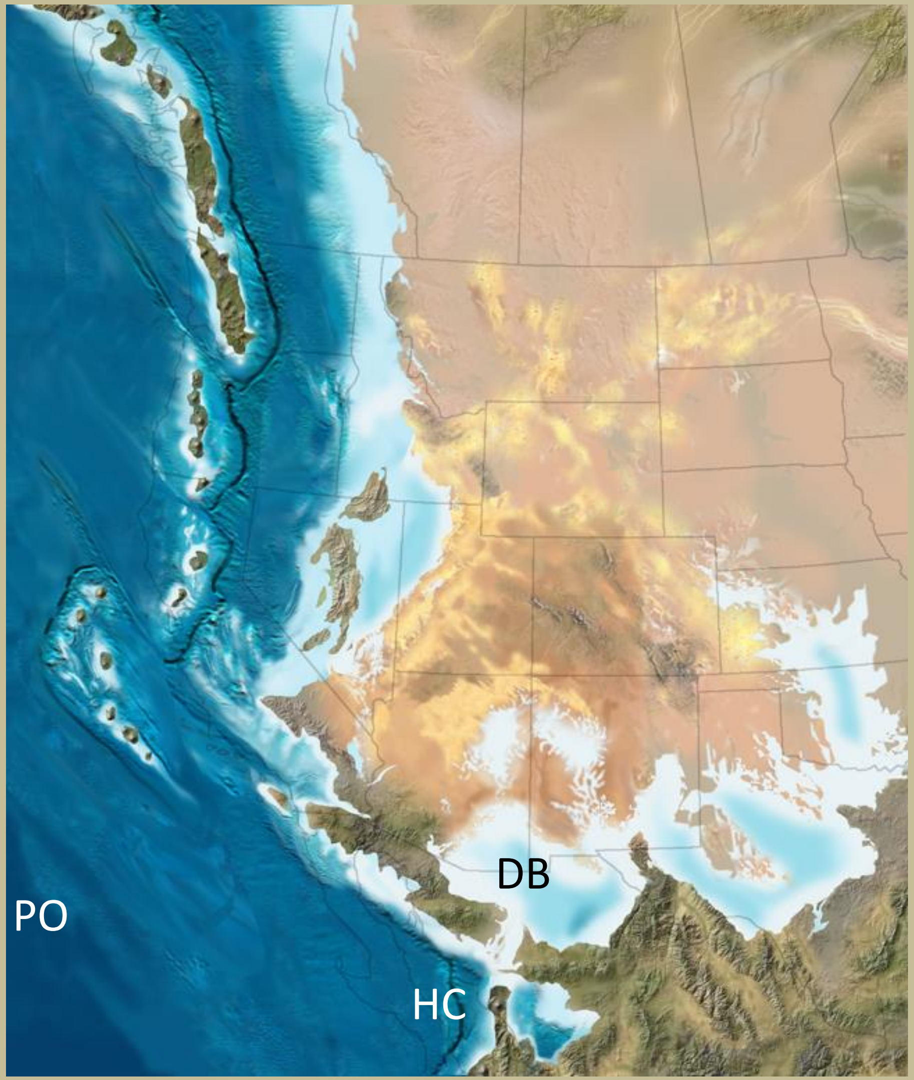
Paleogeography

Permian Salt Basins (after Zharkov, 1984)



Delaware Basin

With falling global sea level, Hovie Channel (HC) inlet began to seal and cut off Delaware Basin (DB) to the Panthalassia Ocean (PO).



Map from Ron Blakey

Ochoan Crisis

Hovie Channel Cut-off,

evaporation exceeds inflow,

and massive deep water and shallow water evaporite deposition results.

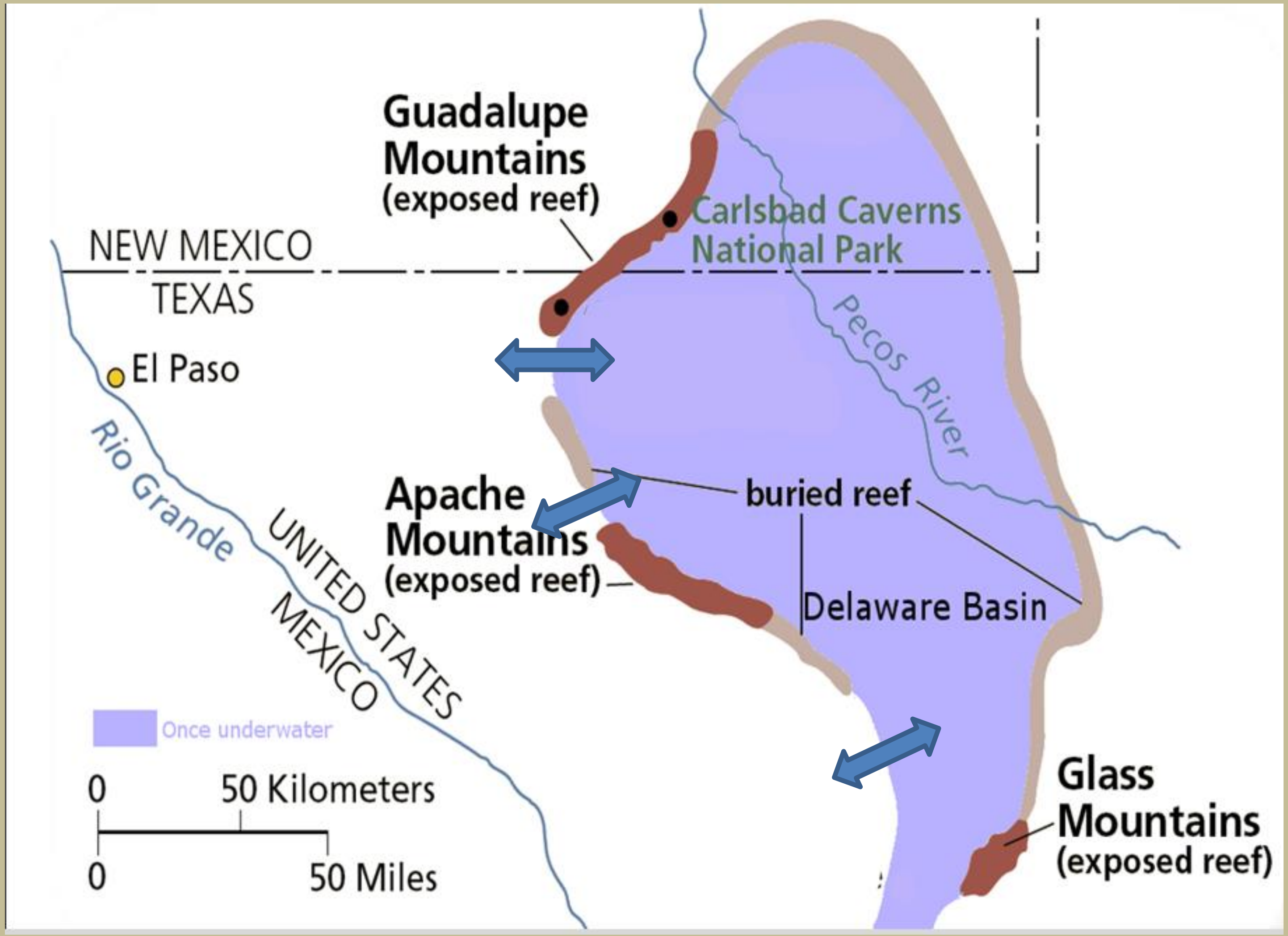
Reefs die, interior basin temperatures rise

(Have you heard this before?)

But where is the Hovie Channel?

But where exactly is the Hovie Channel? ⟺

Some workers say to the West, some to the Southwest, others to the South. The evidence lies in the salt distribution…



Vertical Salt Distribution

Usiglio (1849) Sequence of Salt Precipitation (salts precipitate out of seawater in the reverse order of their solubilities):

5. Sylvite and magnesium salts
4. Halite
3. Anhydrite
2. Gypsum
1. Calcite

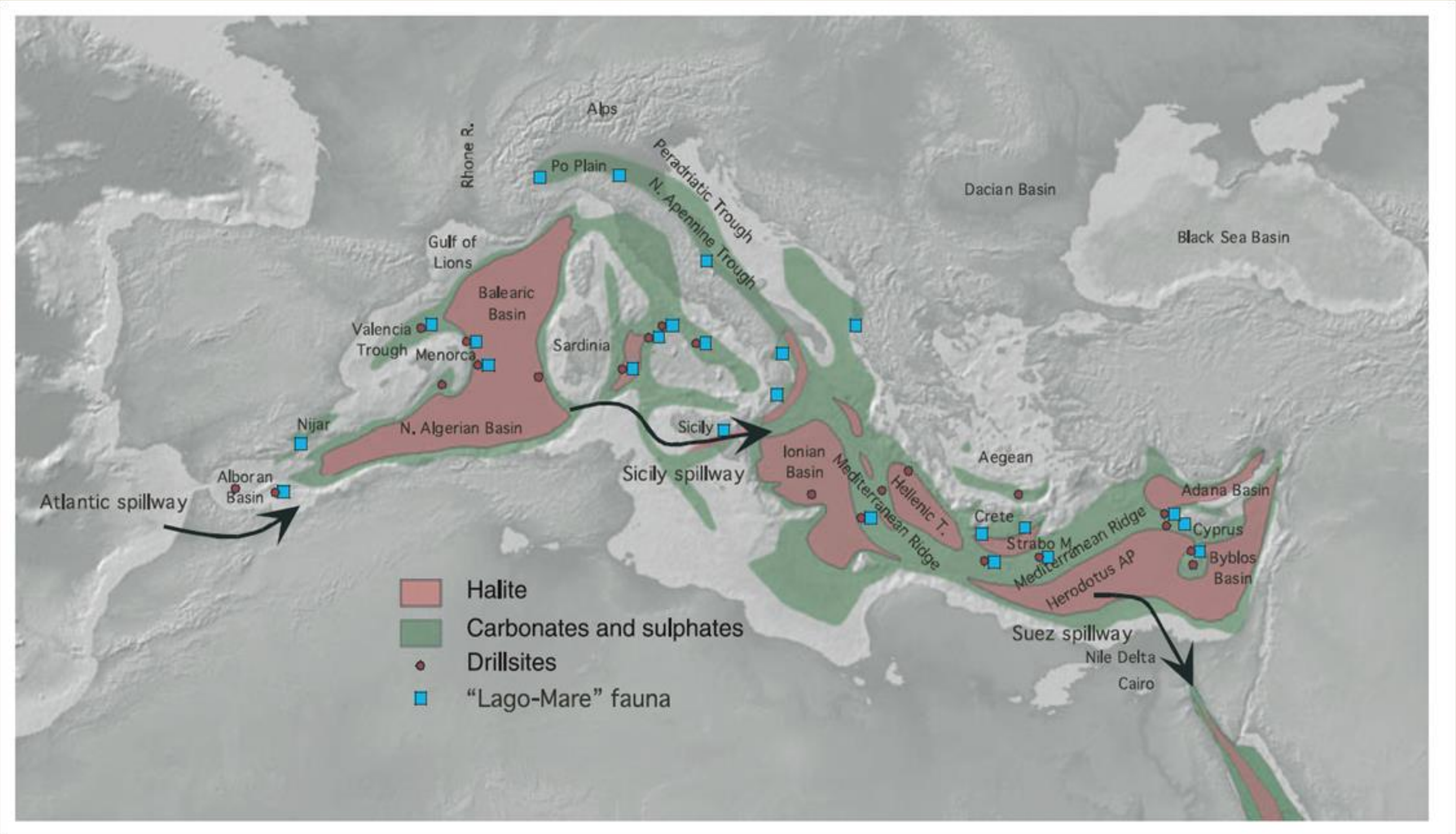




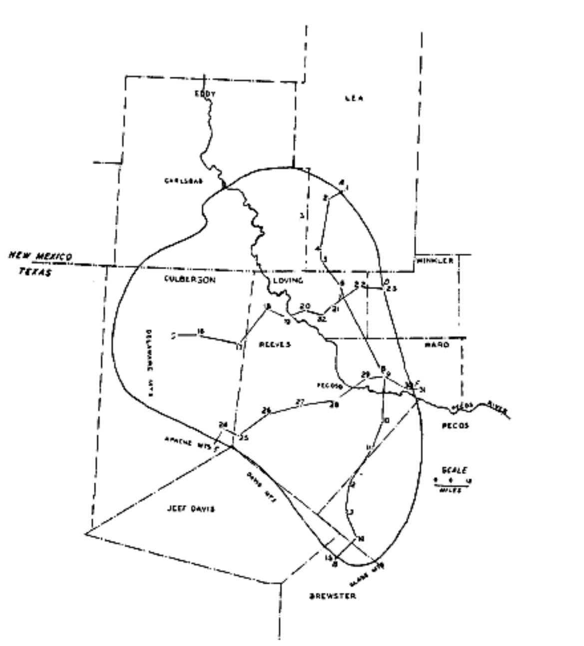
Horizontal Salt Distribution

For the Mediterranean,

in general more soluble salts farther away from ancestral inlet (From Ryan, 2008)



Horizontal Salt Distribution Delaware Basin Similar



SOUTH

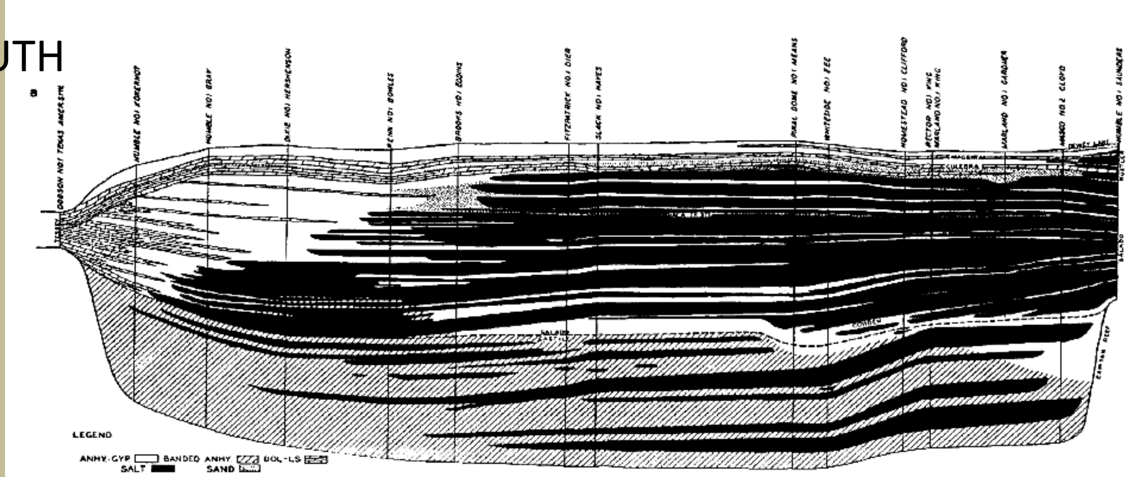
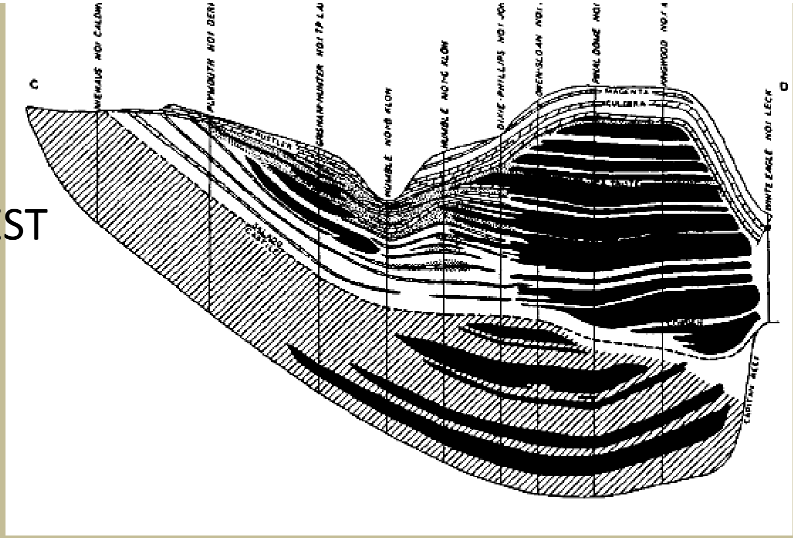


FIG. 2.—Diagrammatic south-north section (BA) of Ochoa rocks in Delaware basin. Line of section shown in Figure 1.

NORTH

WEST



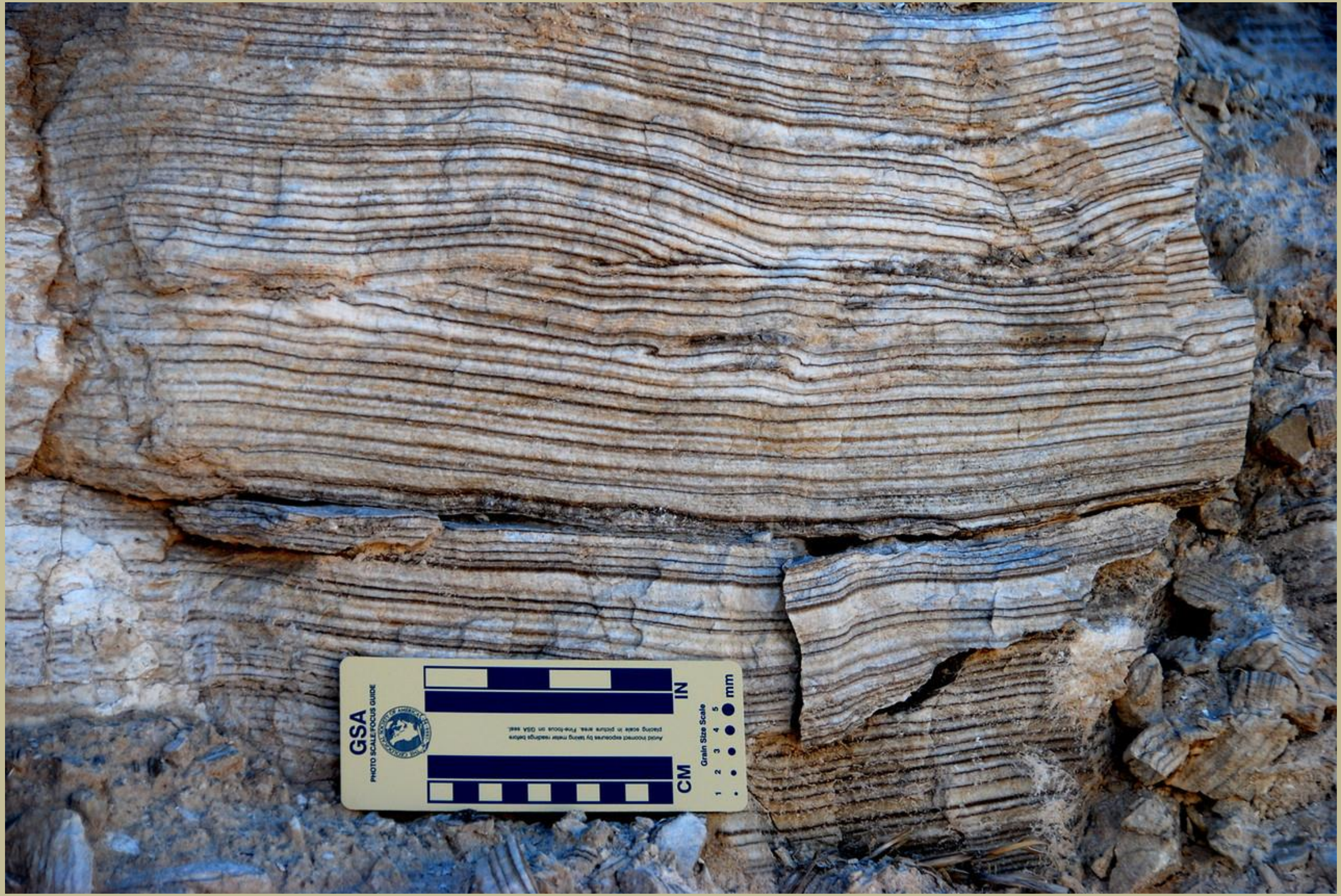
EAST

ANHY.-GYP. BANDED ANHY. DOL-LS
SALT SAND

Usiglio sequence West to East and small variation South to North, IMPLICATION: Hovie Channel Inlet on West, (1944)

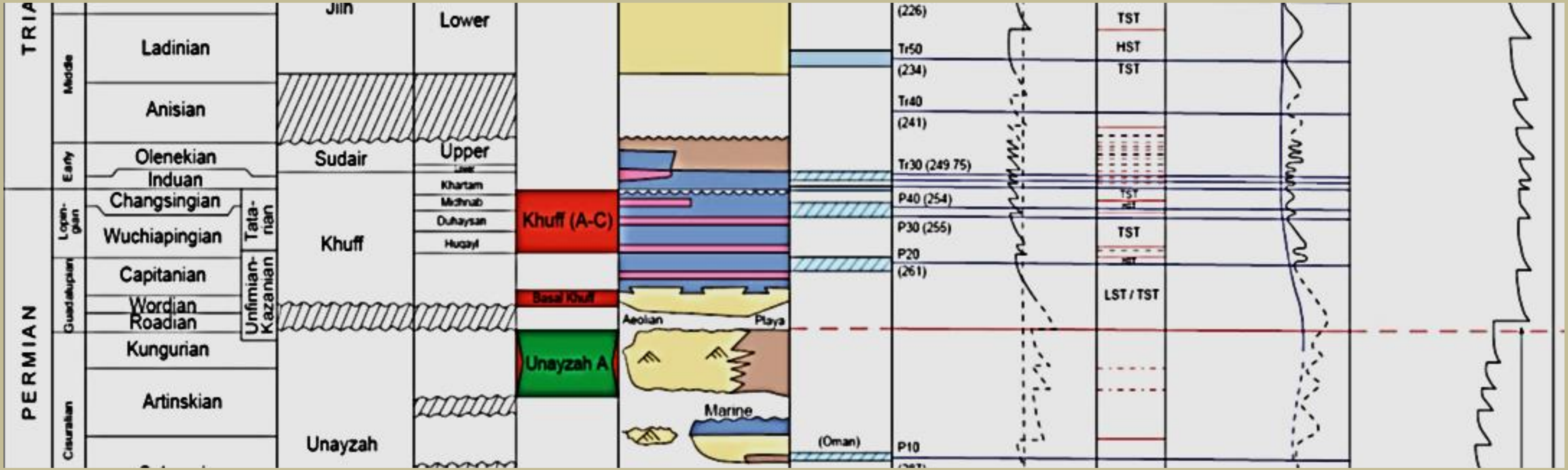
Castille Depositional Rate Rapid

Counting of Castile-Salado laminae and their proposed relationship to Milankovich cycles suggests that Castile-Salado deposition took only 200,000-300,000 yr. (Lucas and Anderson, 1994), ½ the tıme of the Messınıan!



Saudi Aramco PermoTriassic Global SL Curve

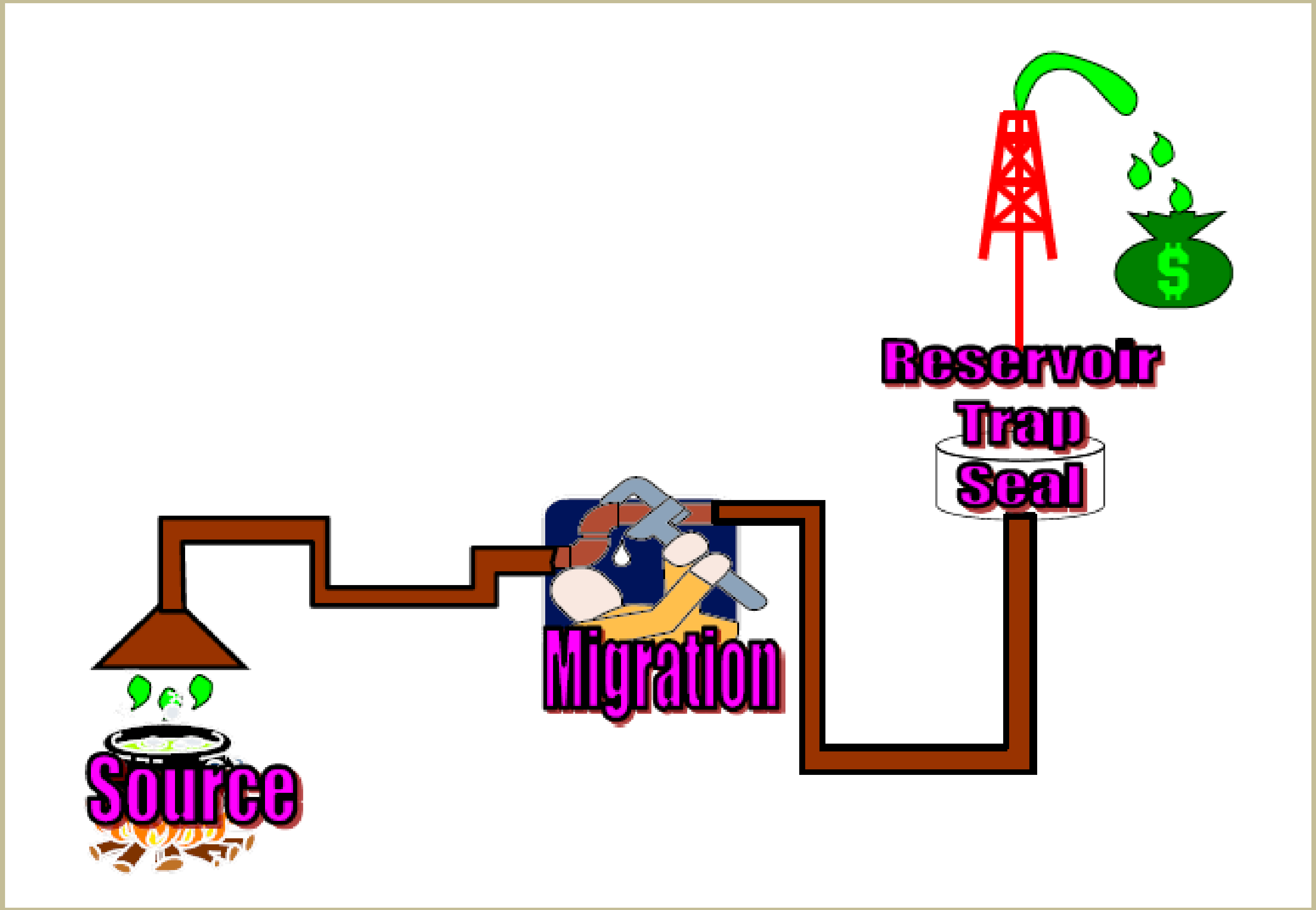
Note global fall at onset of Ochoan, there is a marine re-invasion, e.g. Rustler Dolomite. But was it gentle?



The Marine Reinvasion

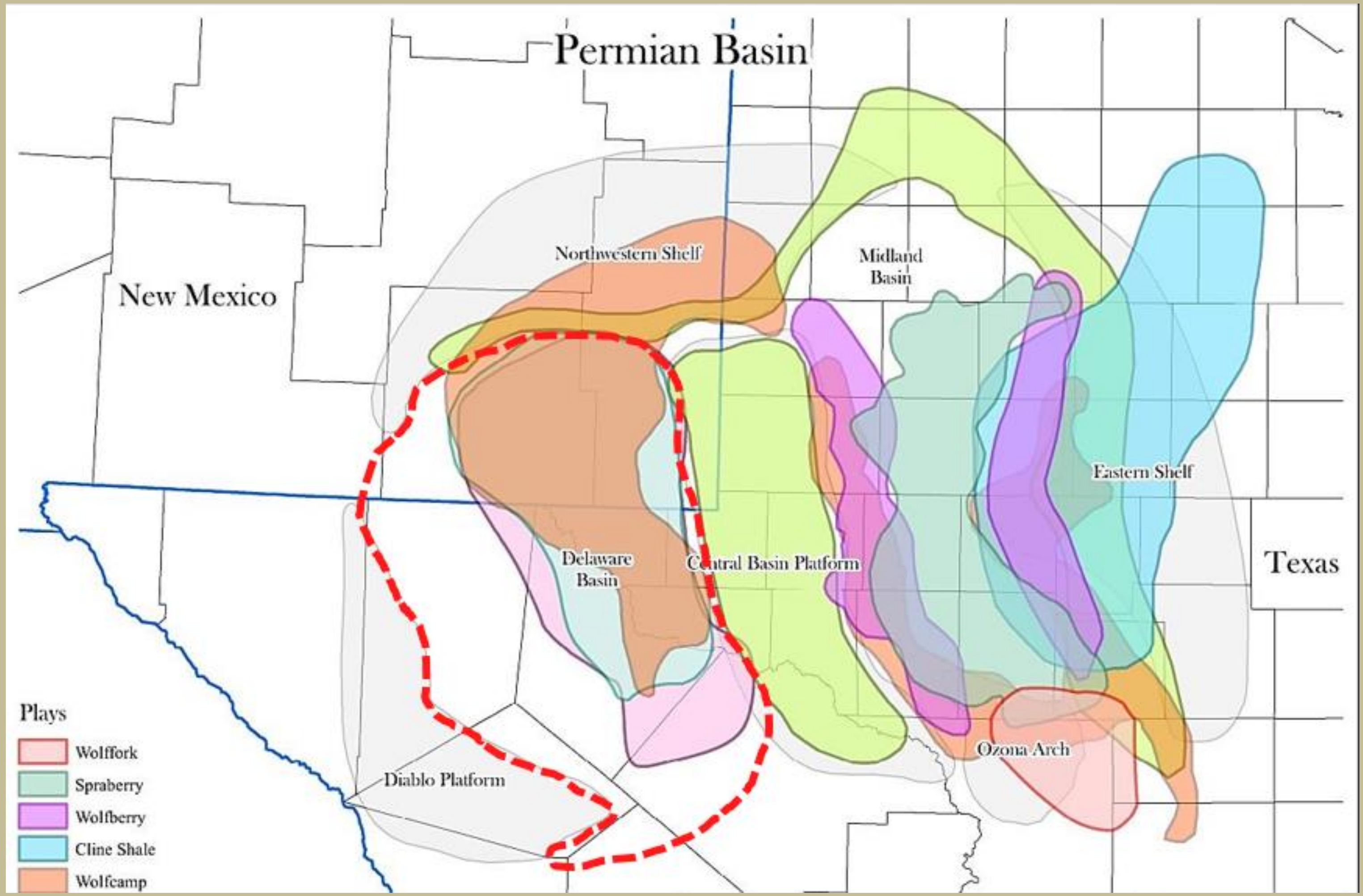
Or a torrent? Tremendous amount of Castille and later evaporites are missing…when did they erode? Subaqueously during end of the Ochoan sea level re-entry or subaerially during the Laramıde (?) uplift?

EFFECTS ON PETROLEUM SYSTEM



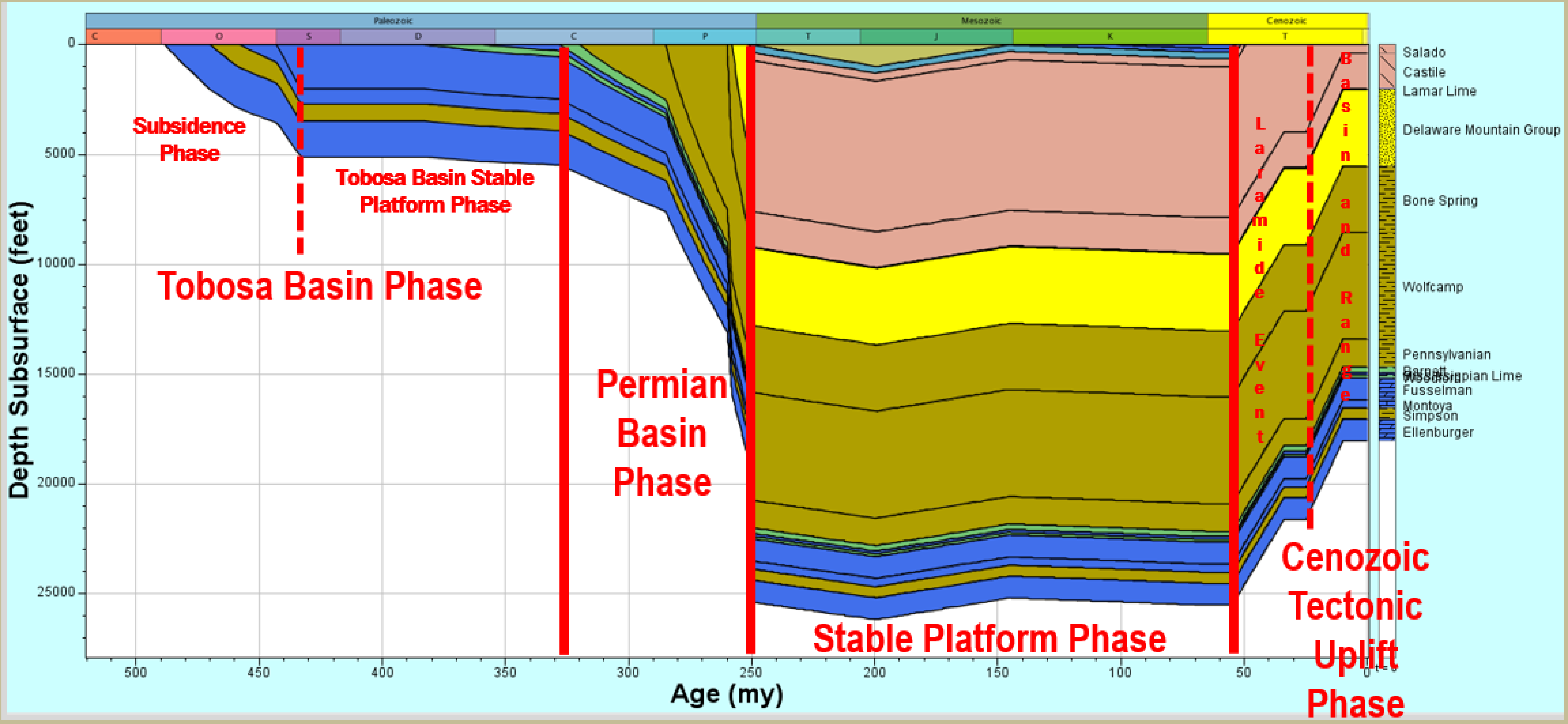
Present Permian Basin HC Exploration

Dashed red outline indicates Delaware Basin



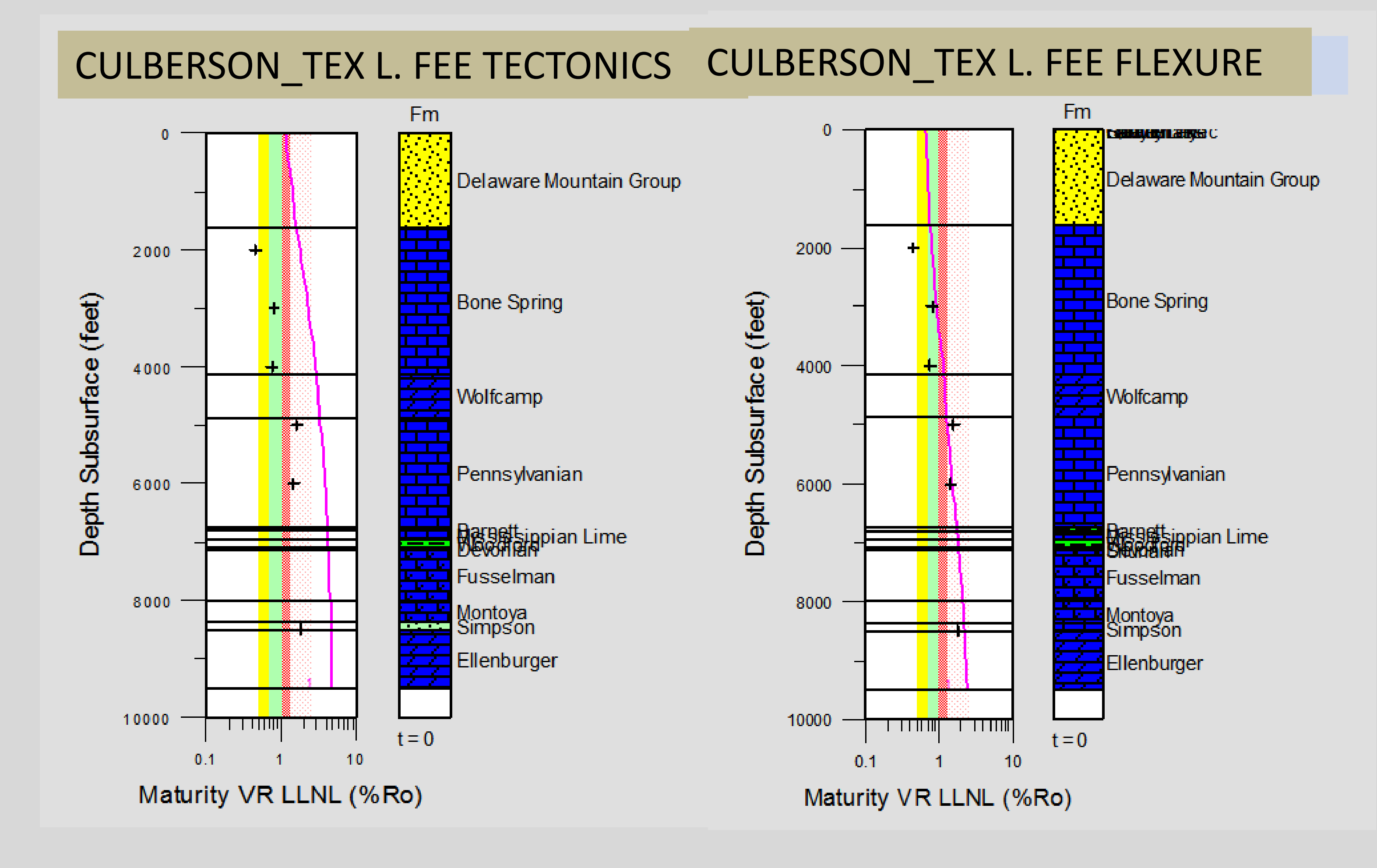
Modified from Drilling Info, 2013

MAJOR TECTONIC PHASES FROM TYPE WELL BURIAL HISTORY

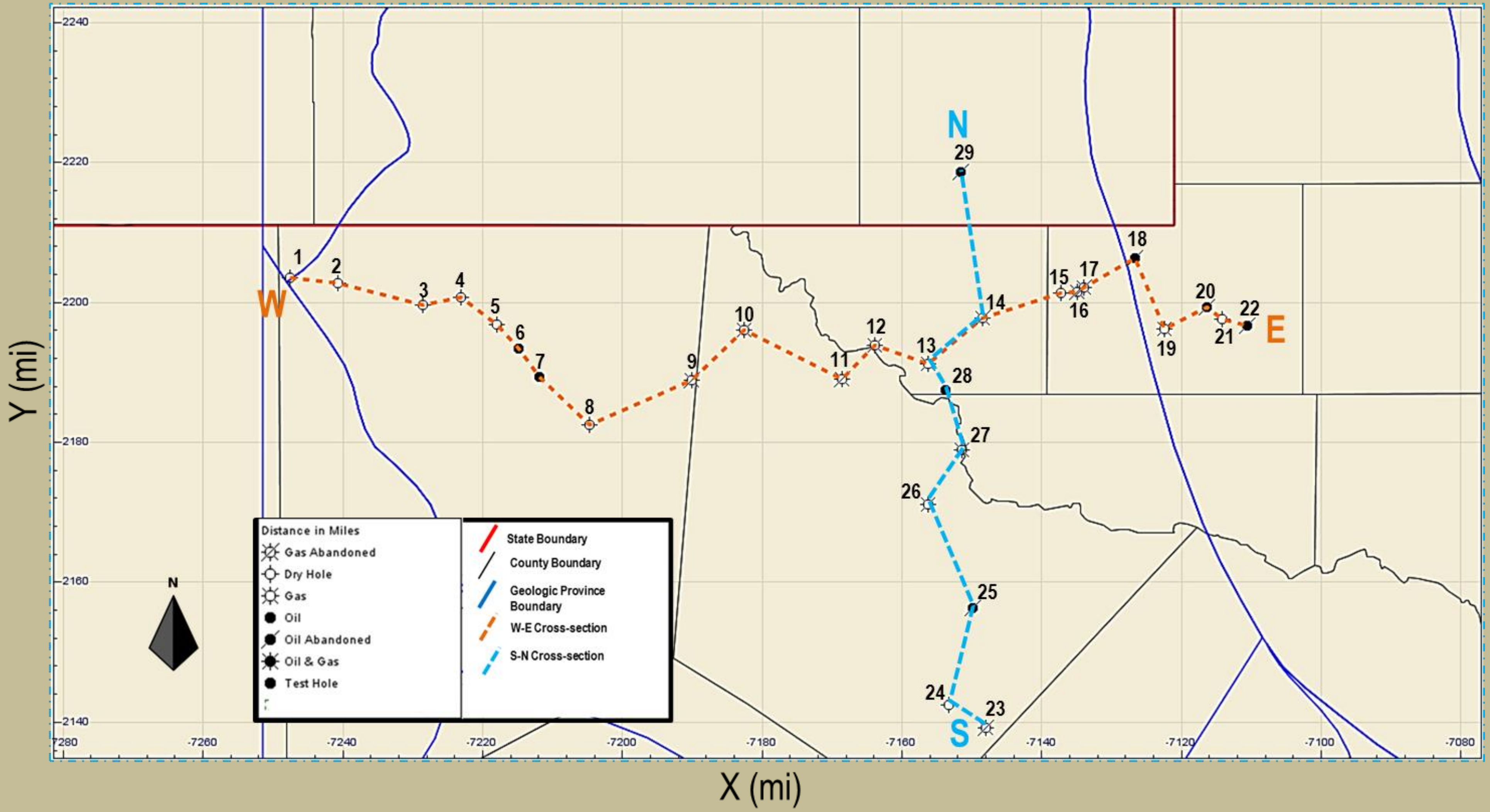


BUT IT IS NOT JUST TECTONICS…

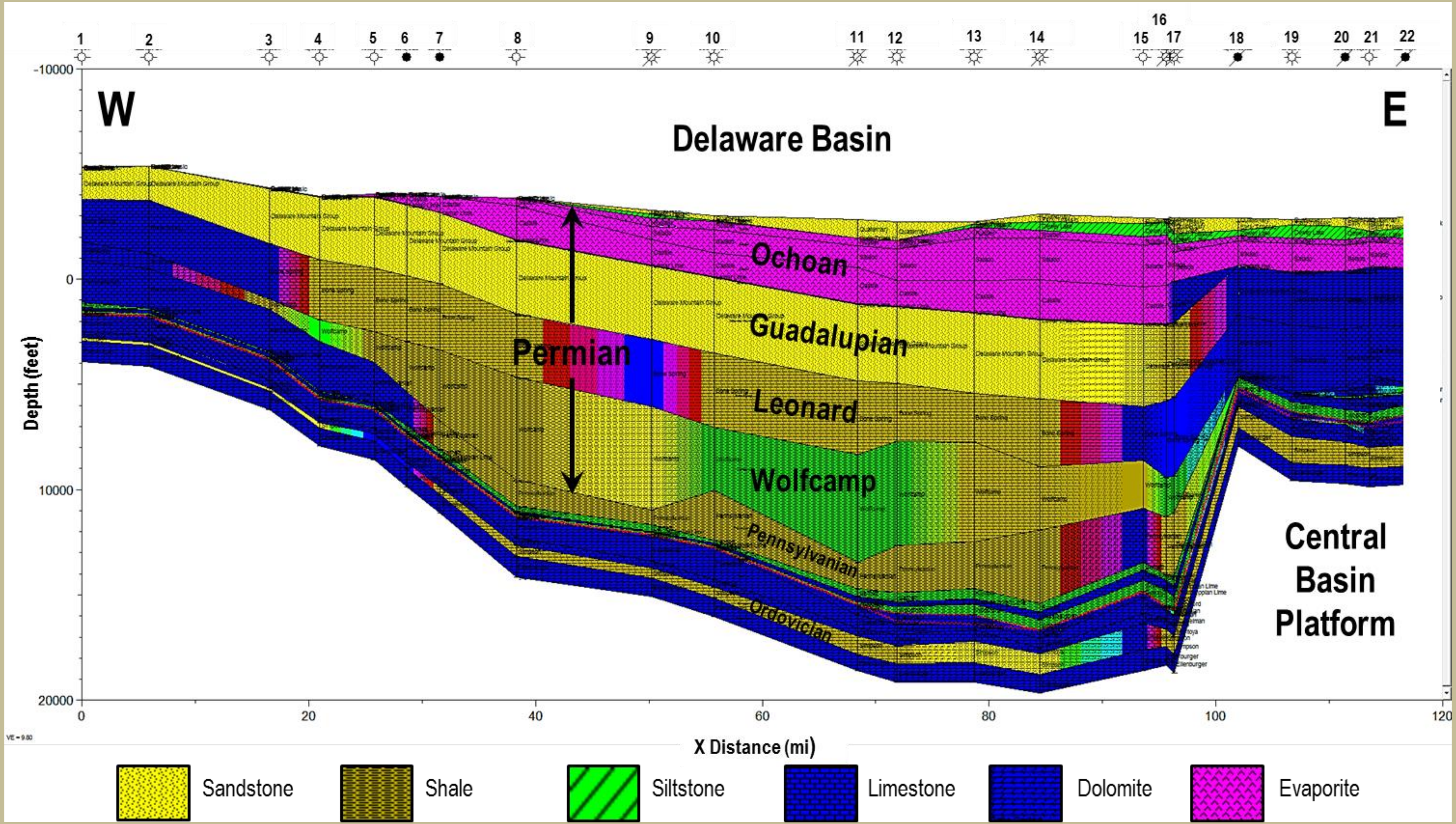
So analogous to the Mediterranean, there are non-rifting tectonic influences



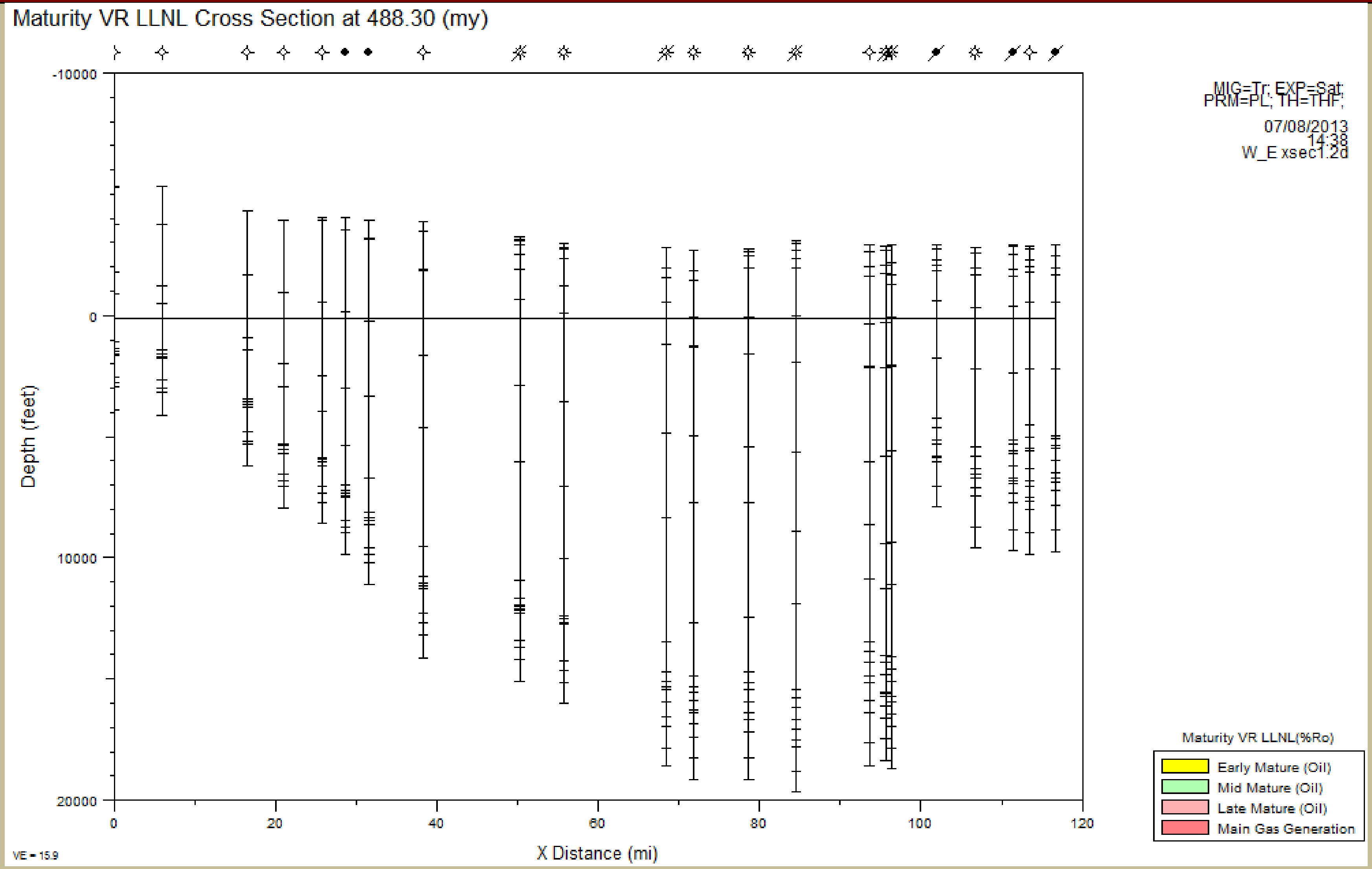
Maturity Modeling



2-D Subsidence Maturity Model



2-D Subsidence Maturity Model



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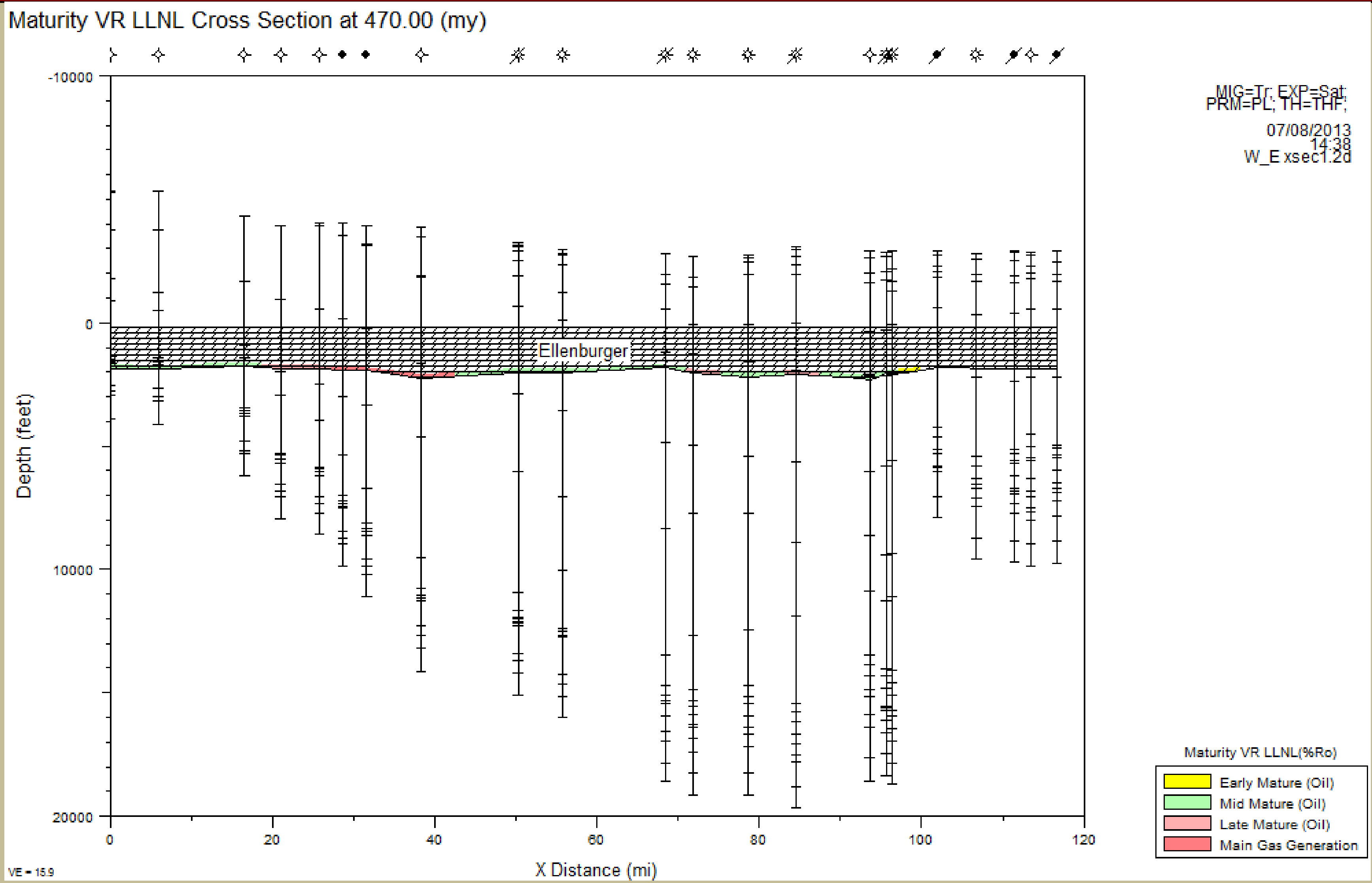

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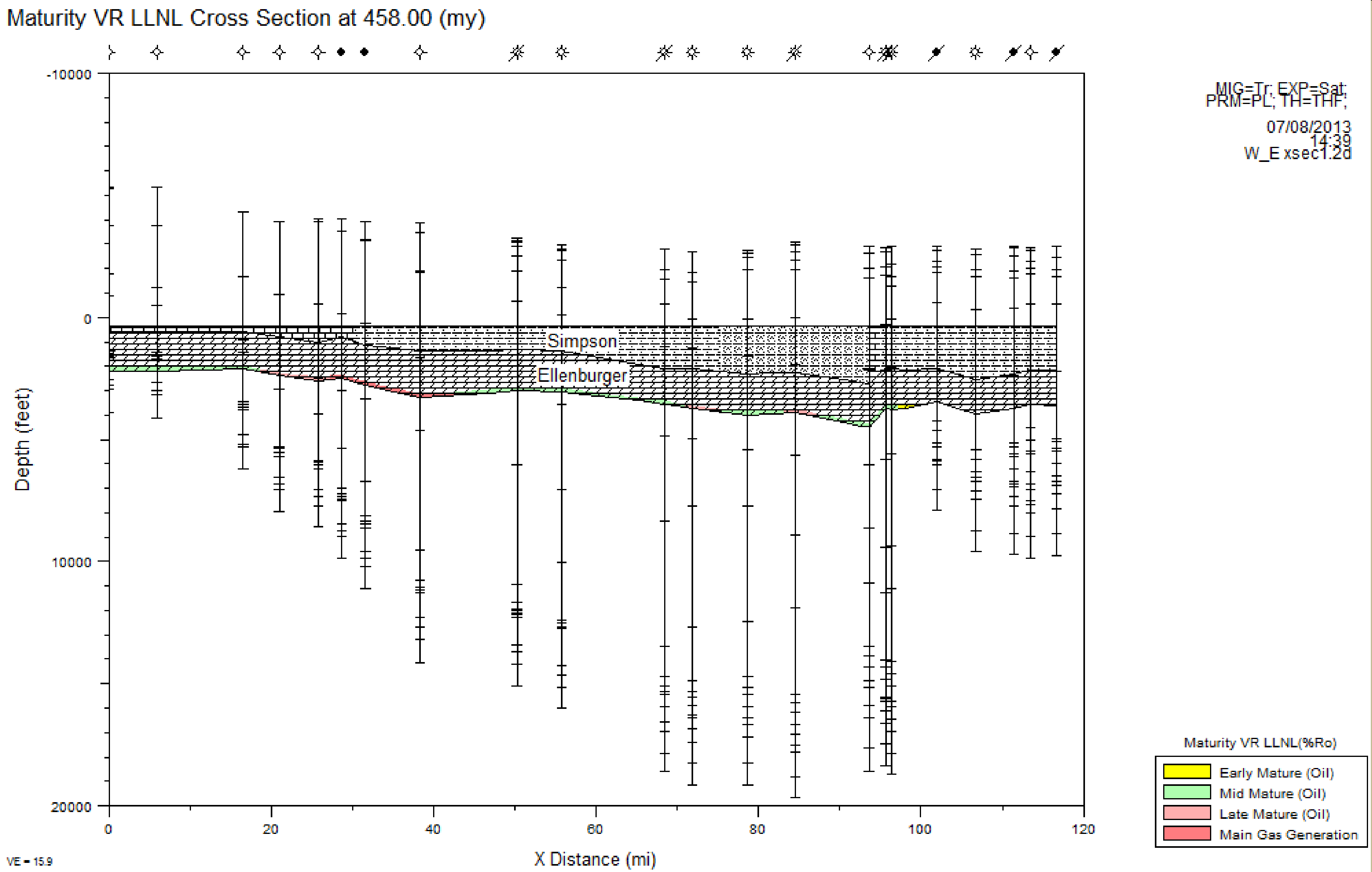

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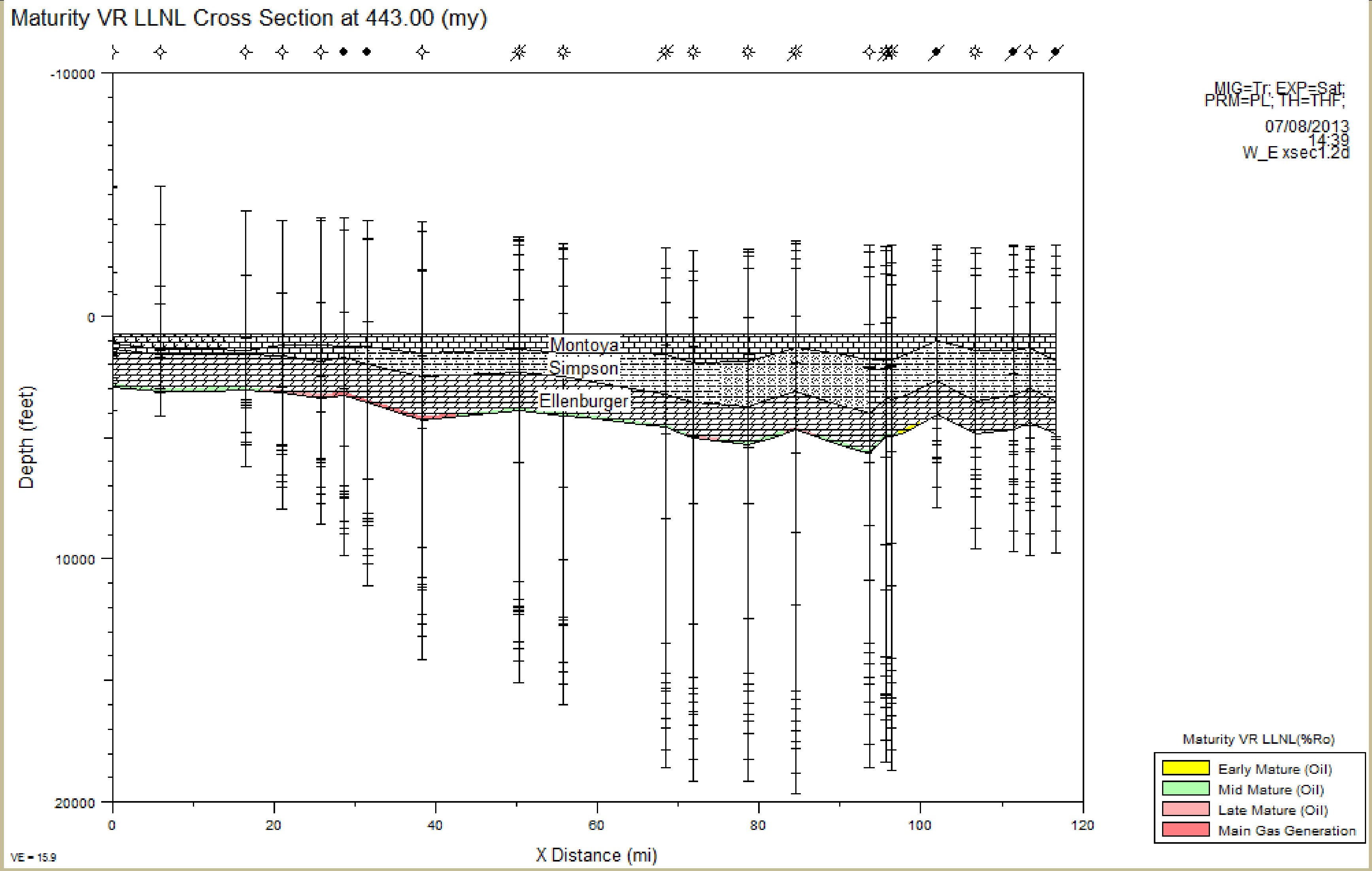

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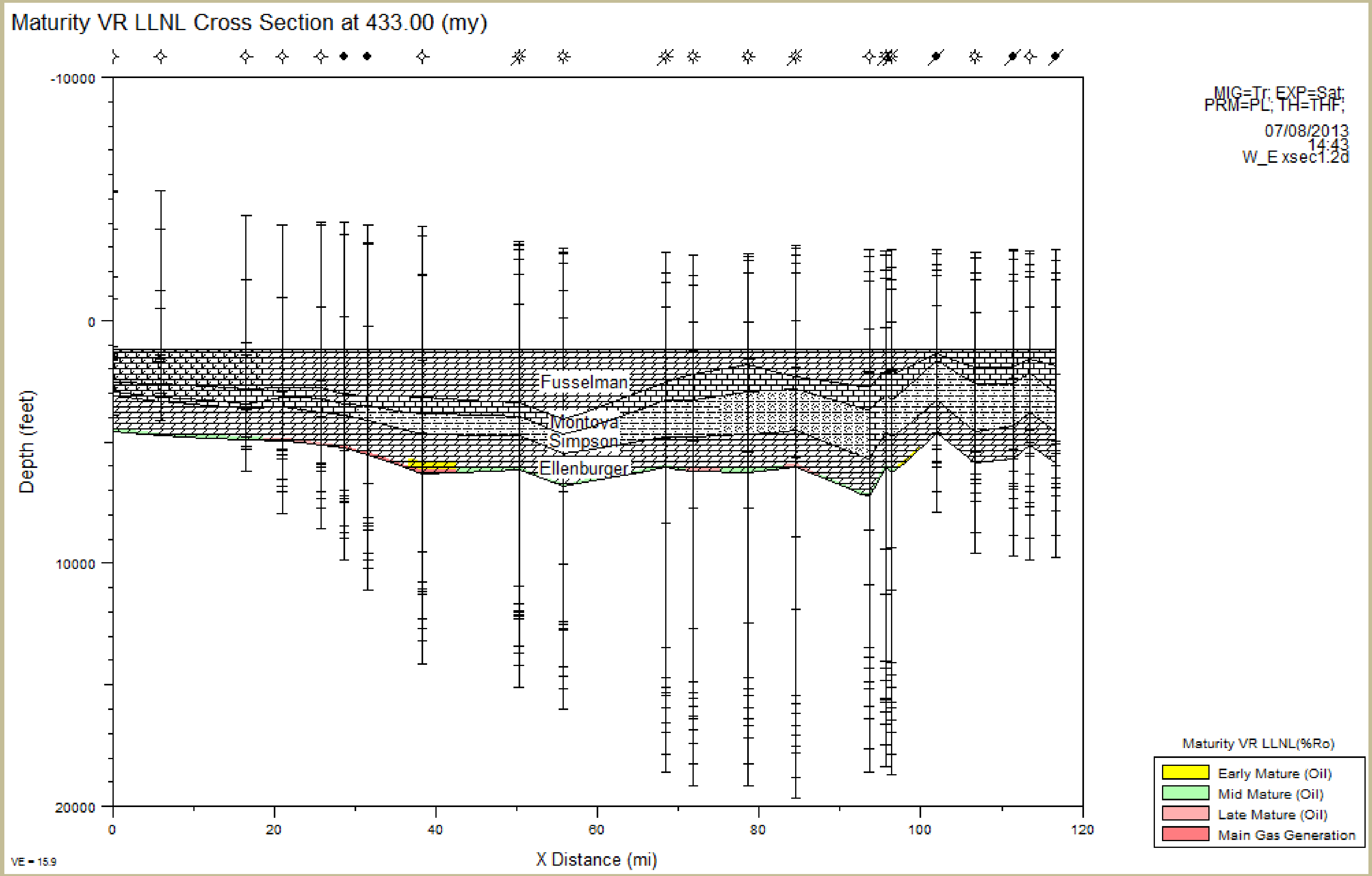

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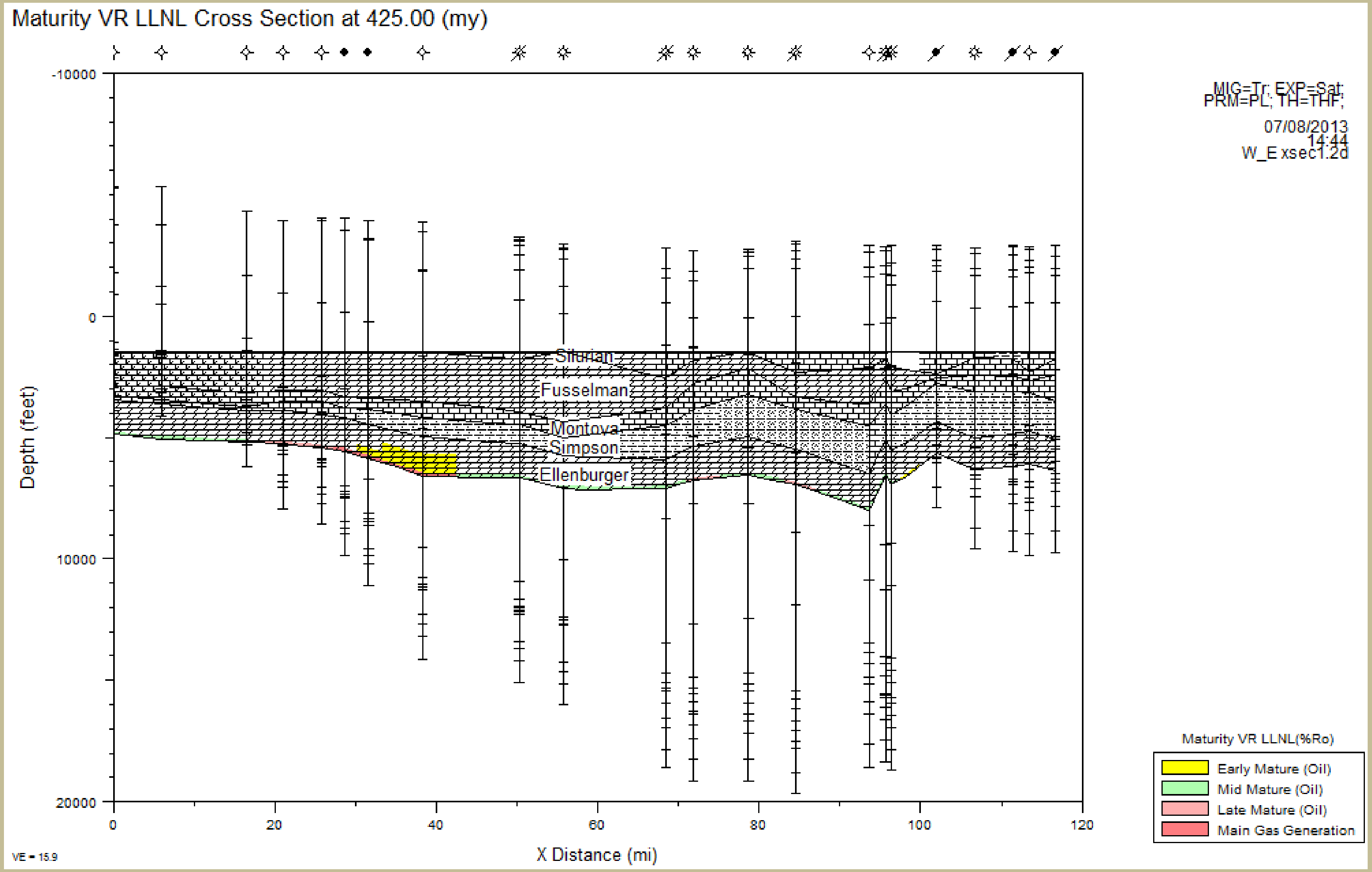

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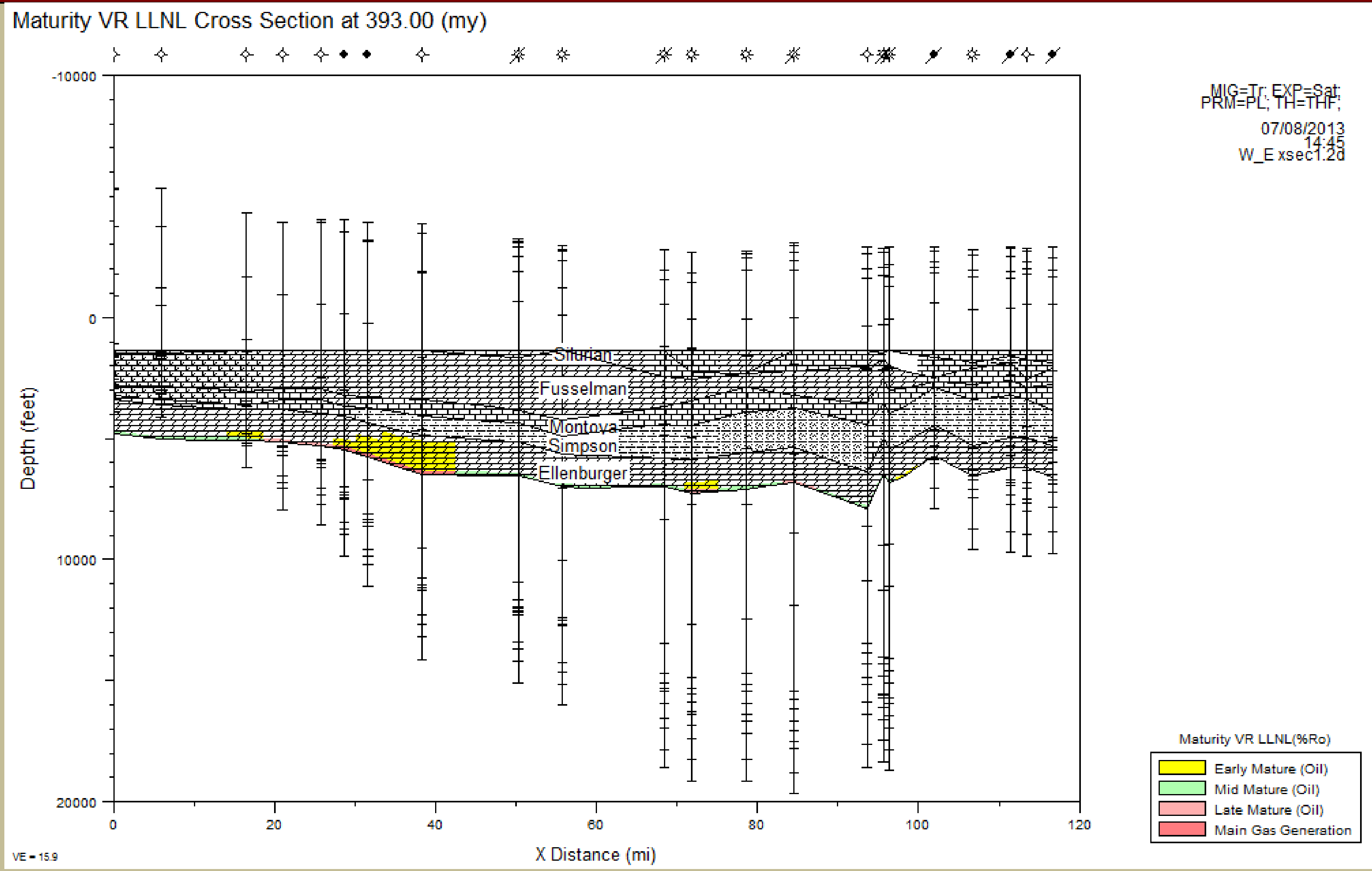

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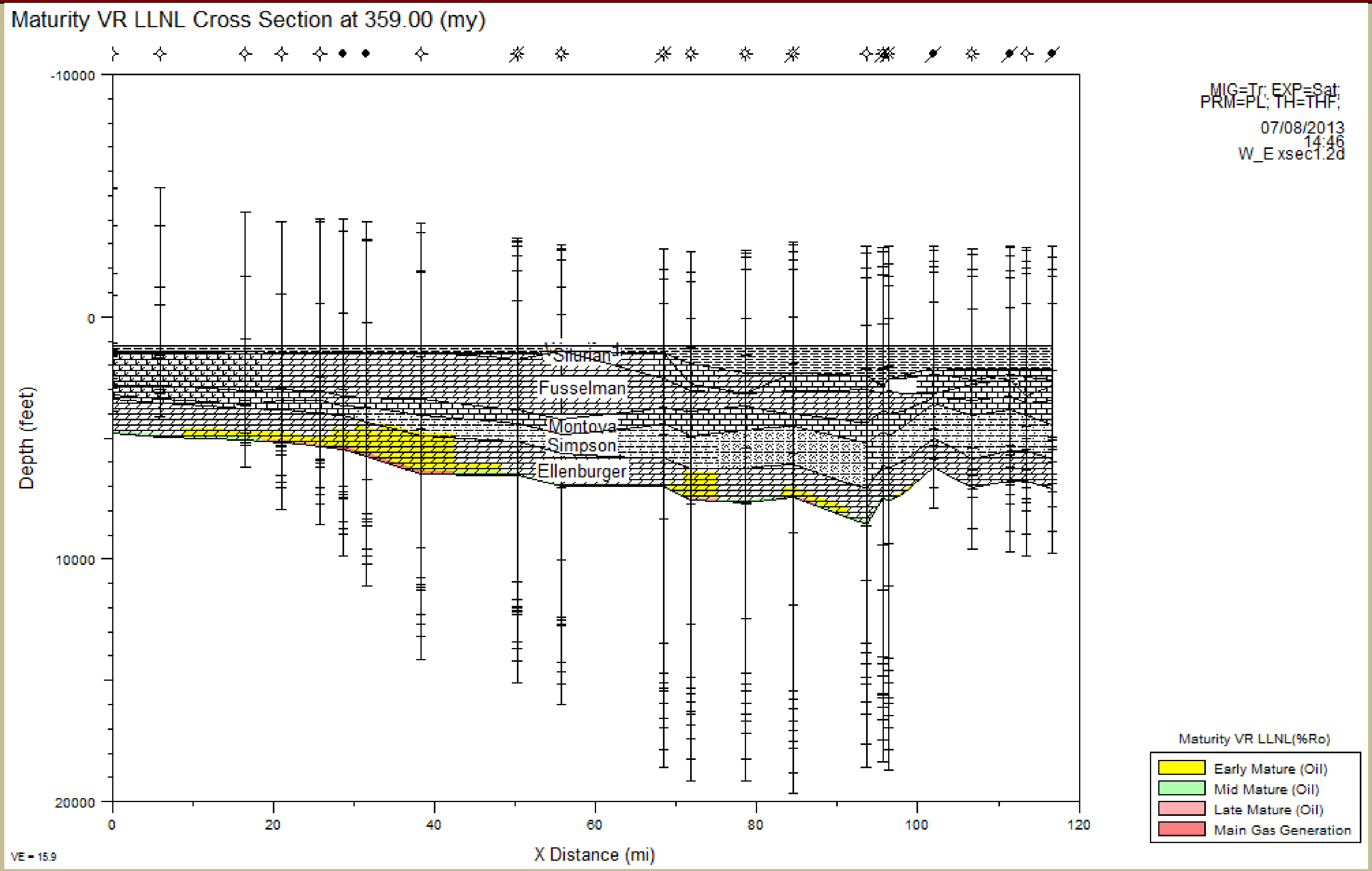

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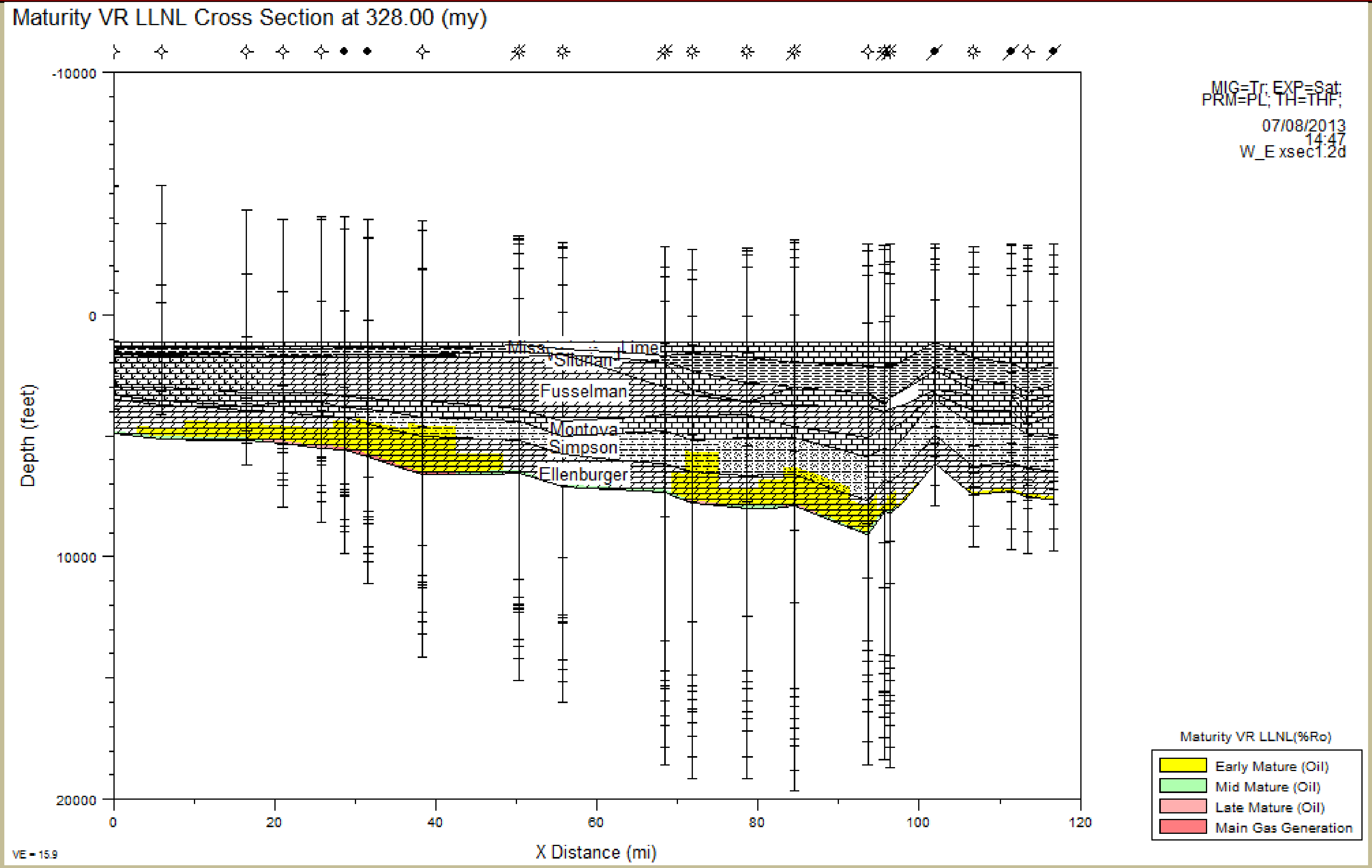

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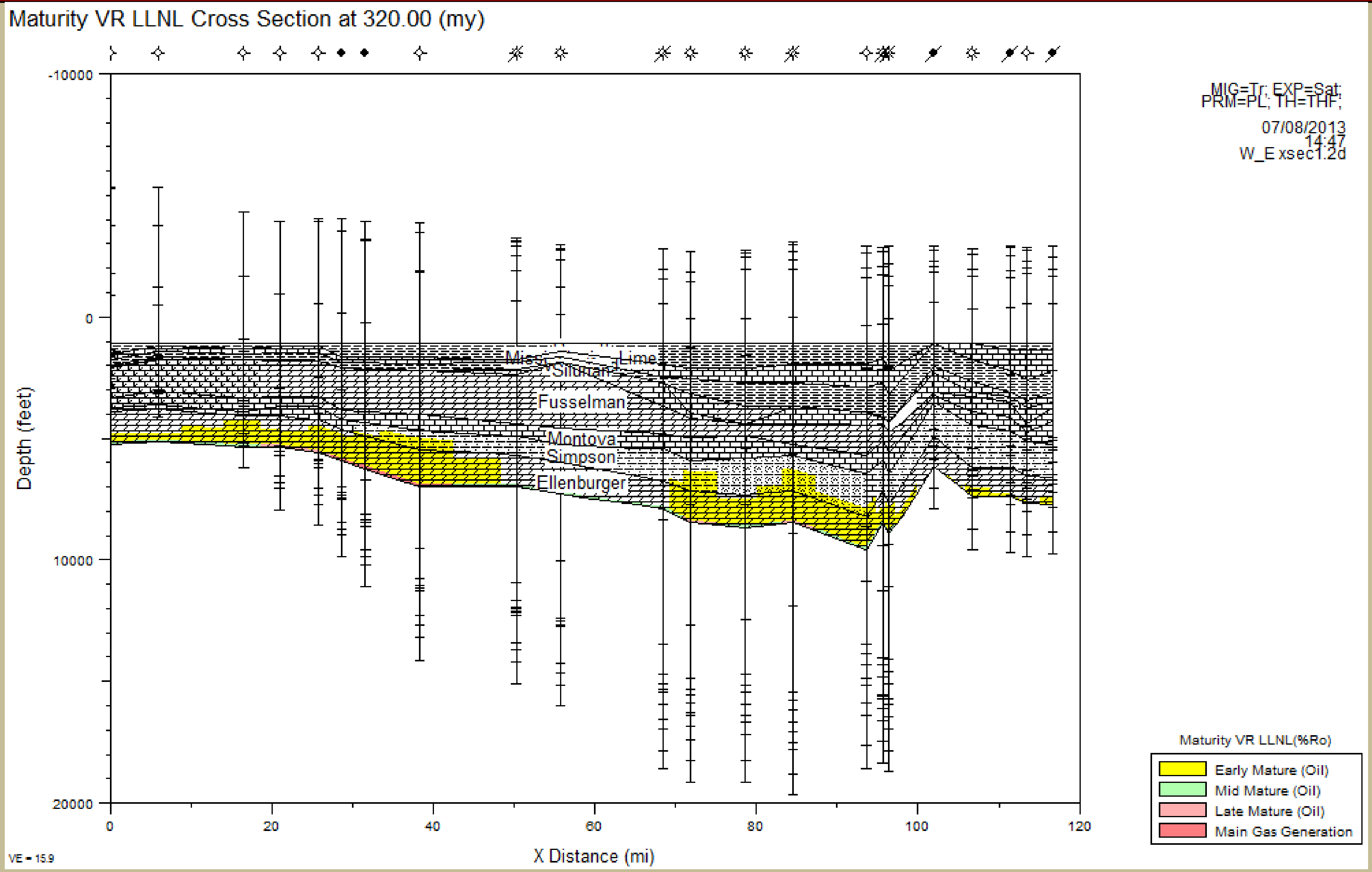

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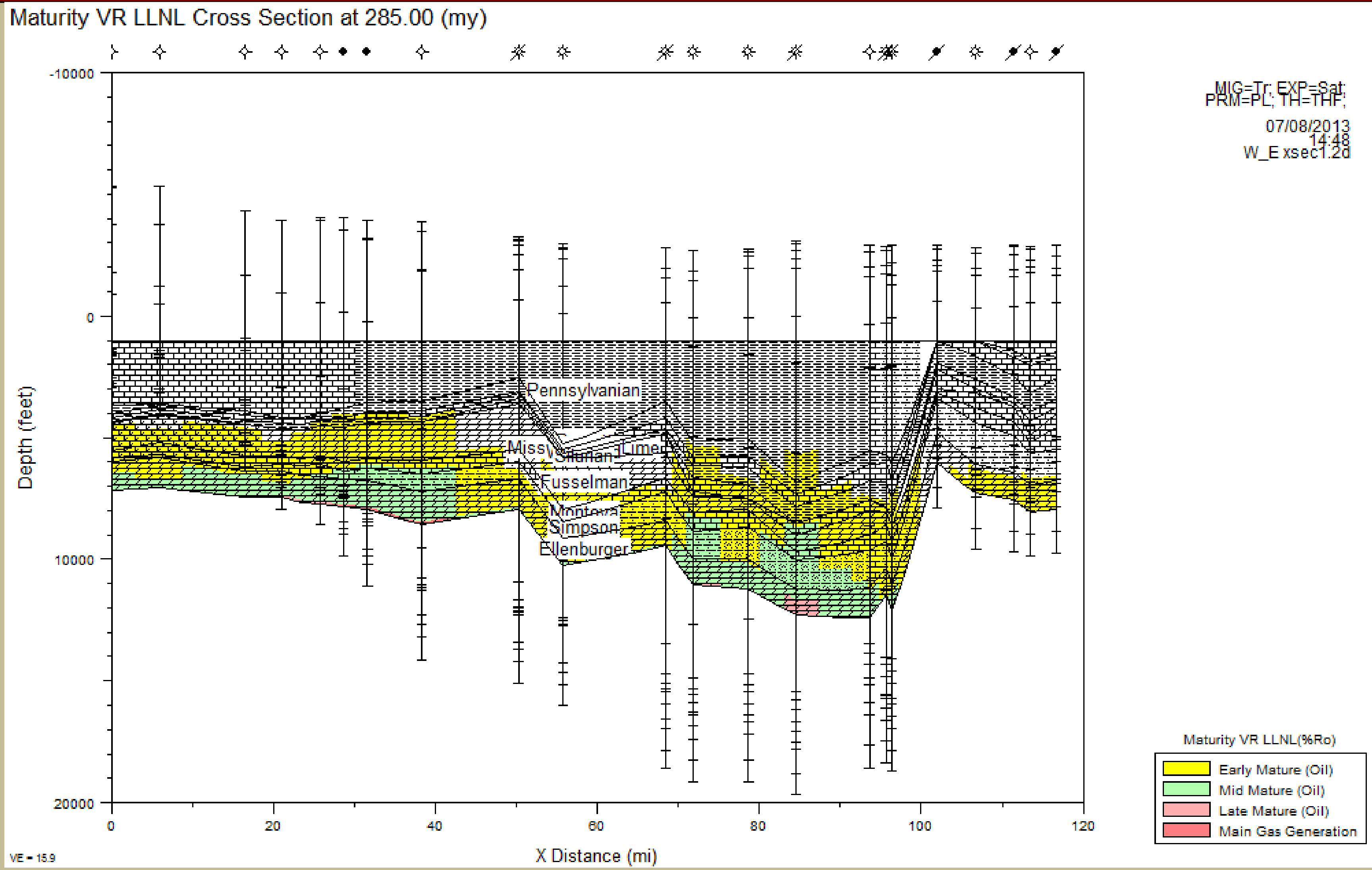

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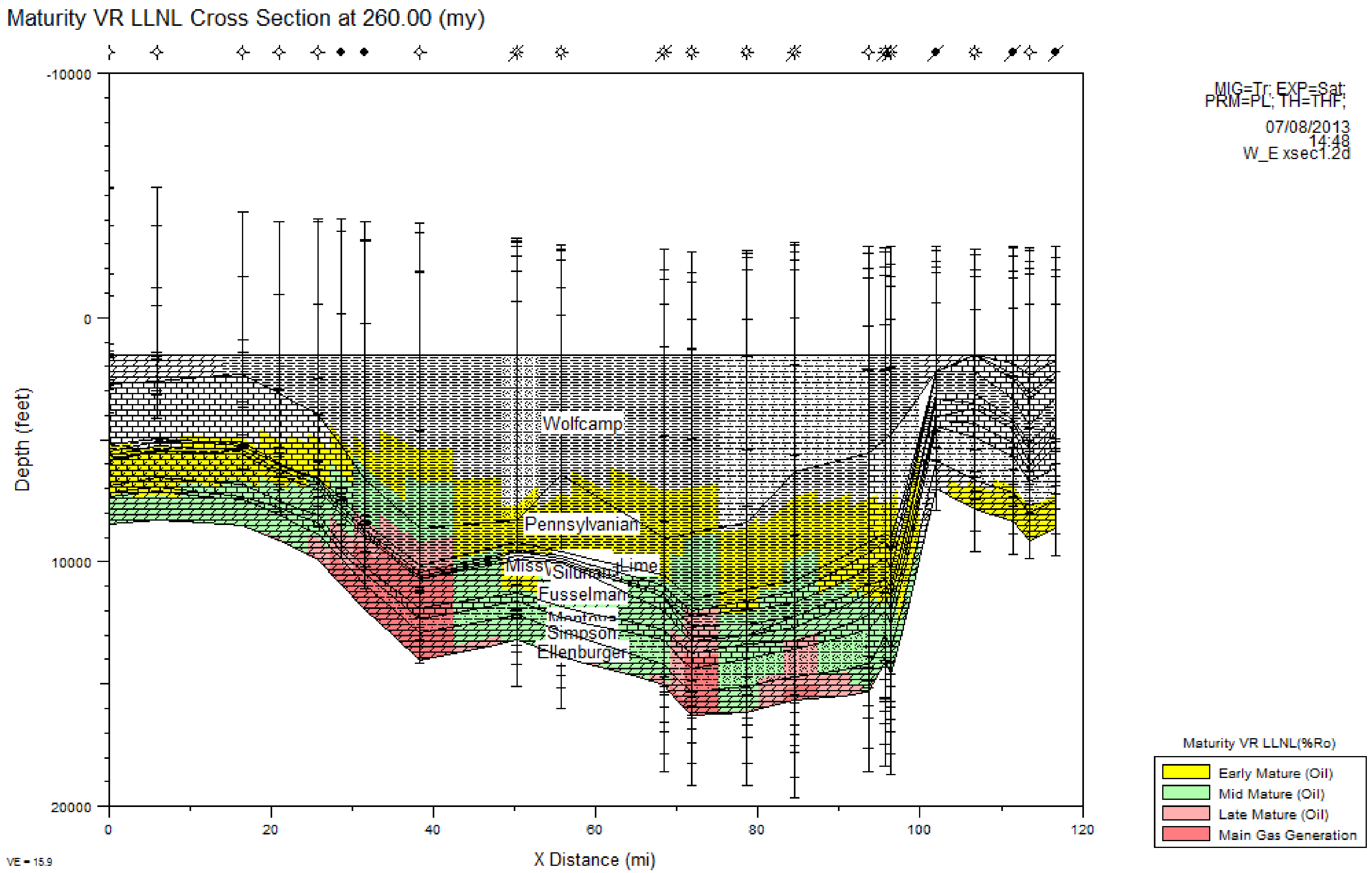

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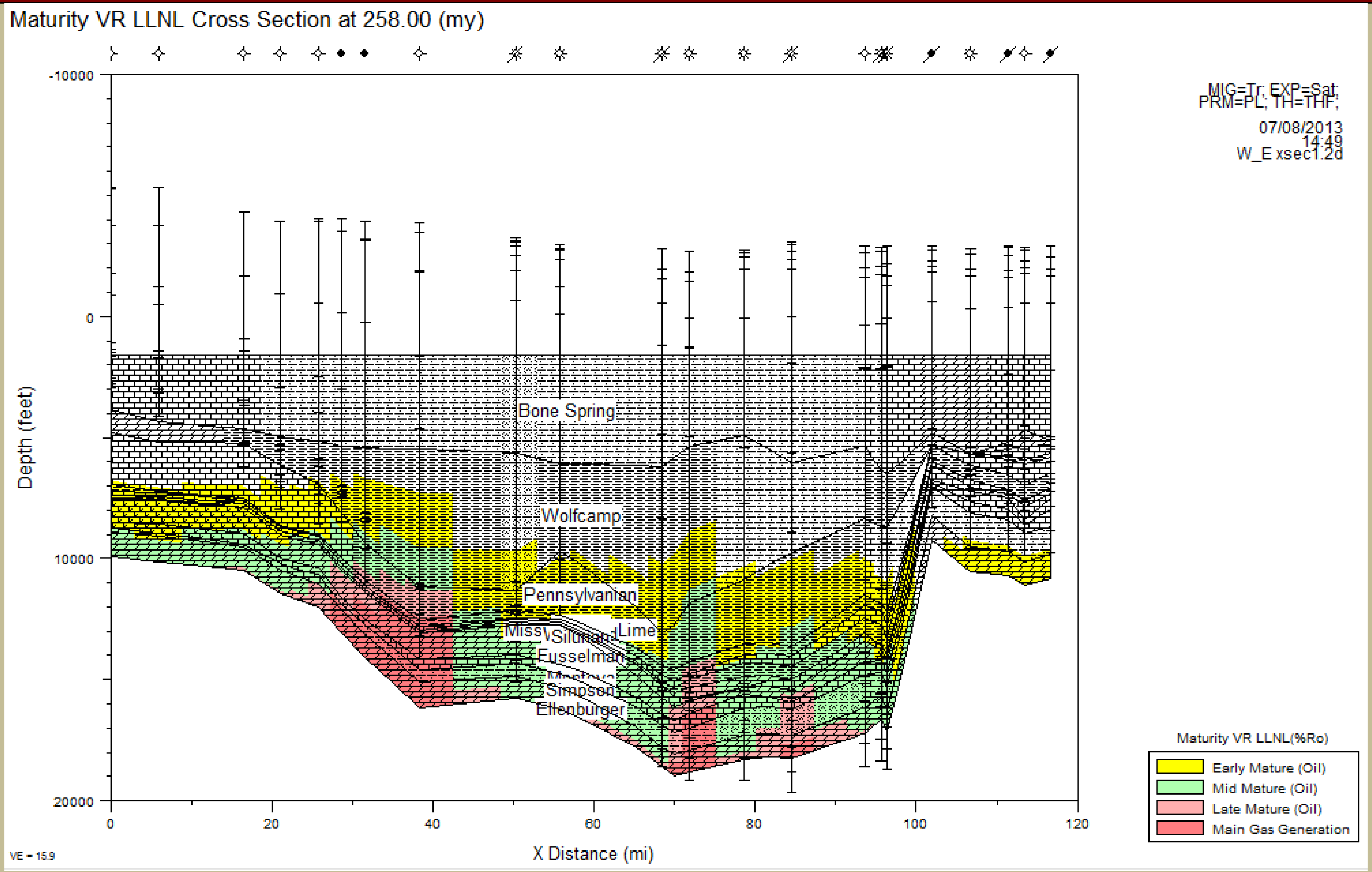

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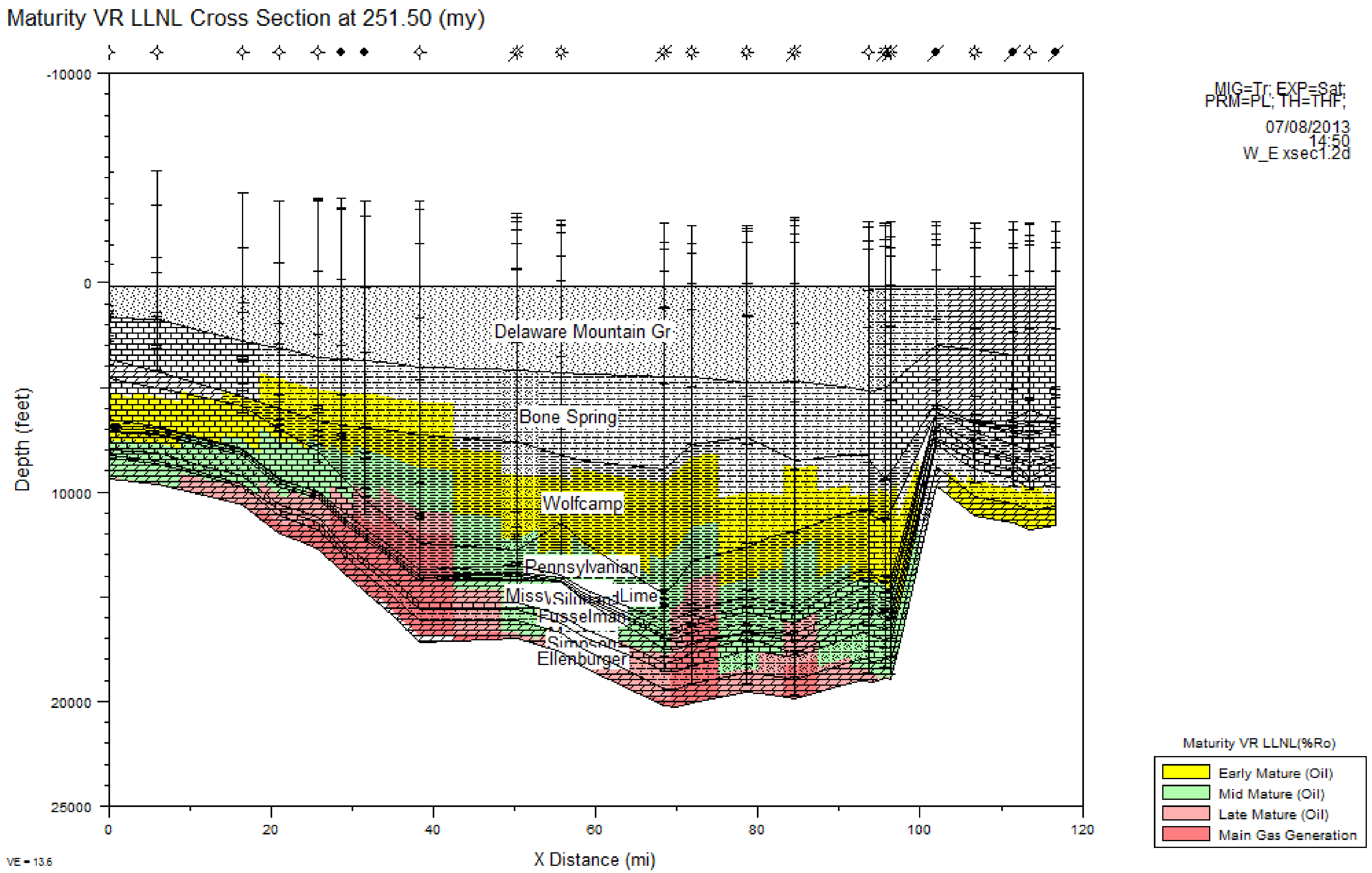

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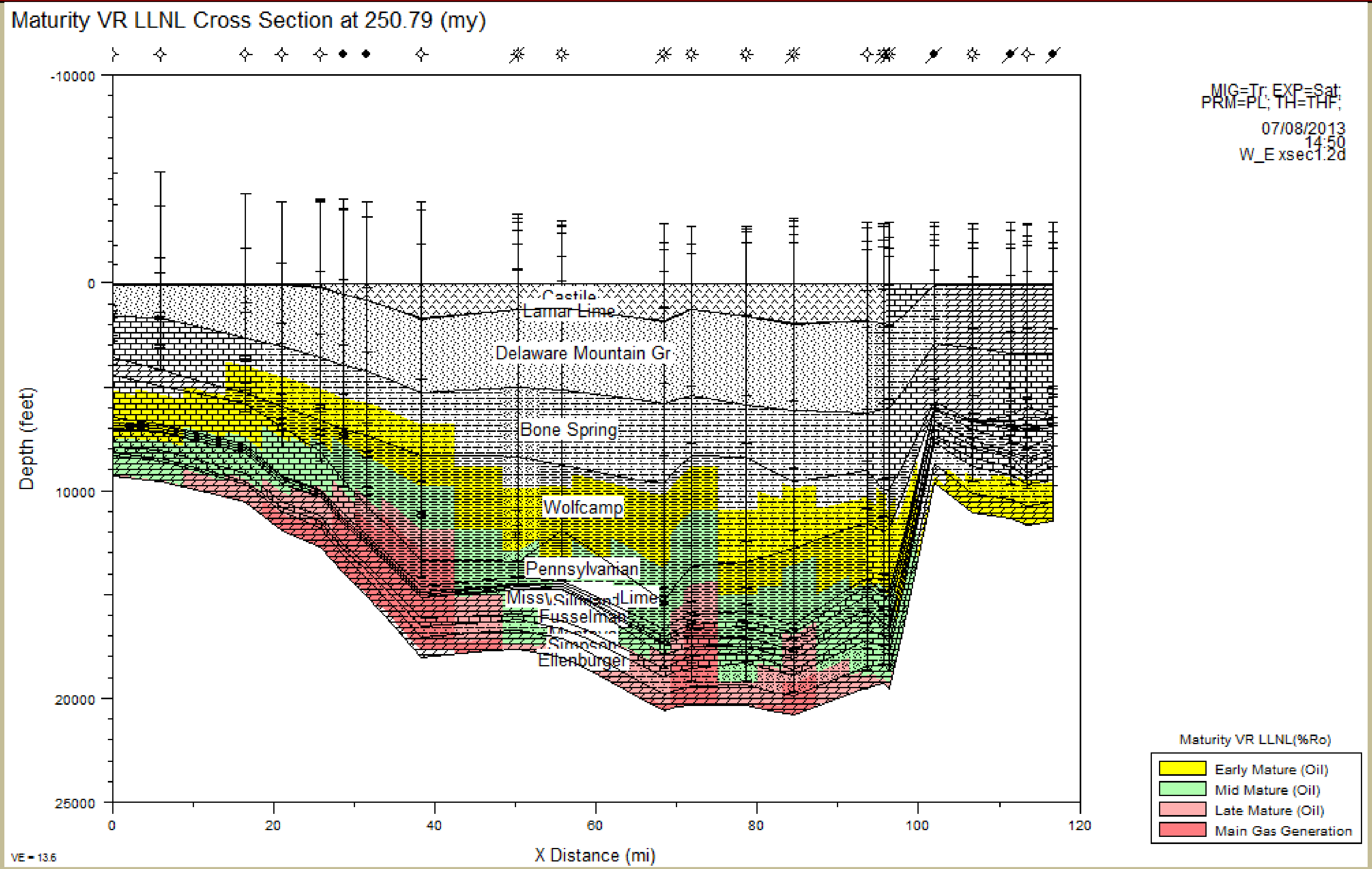

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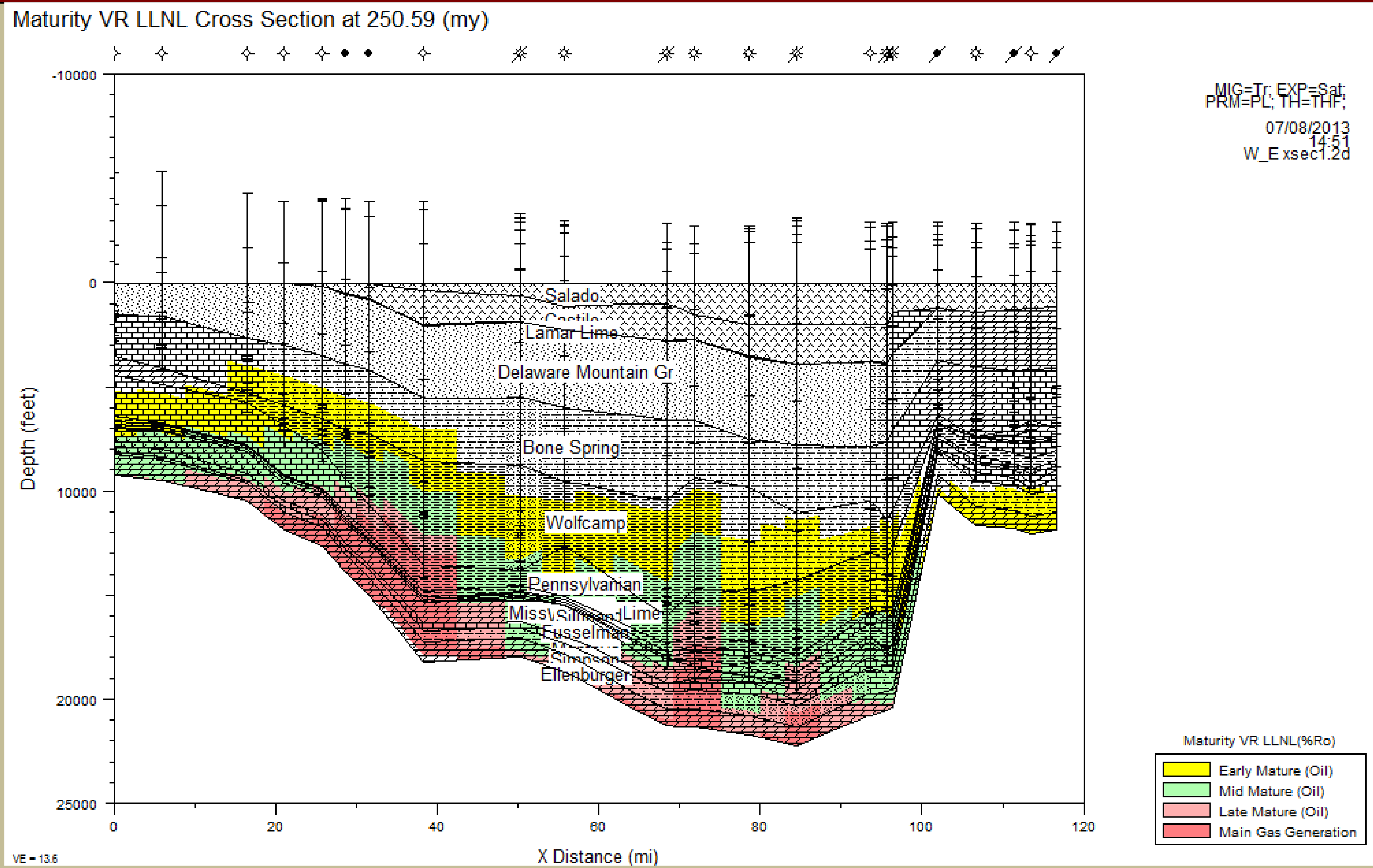

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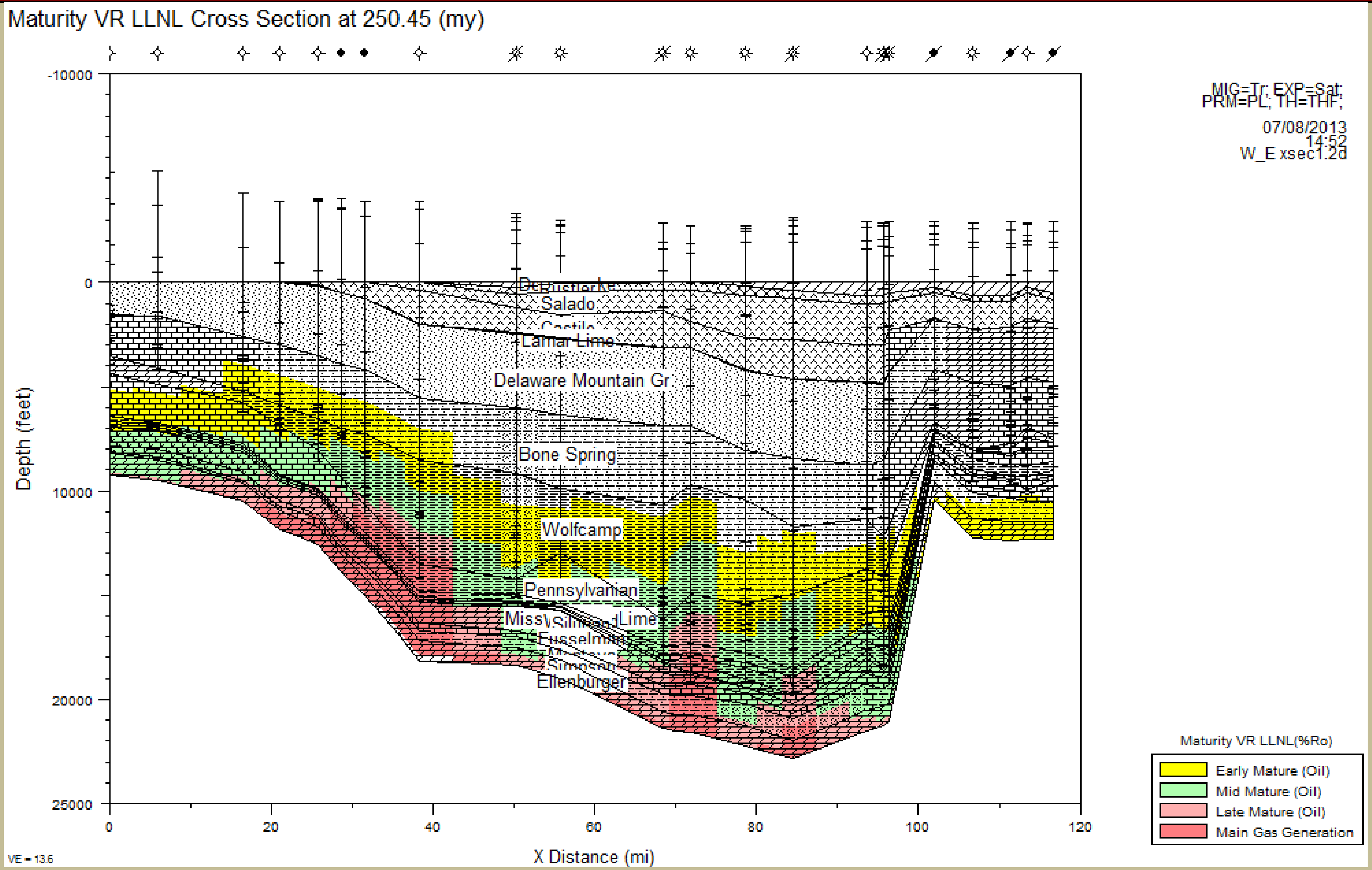

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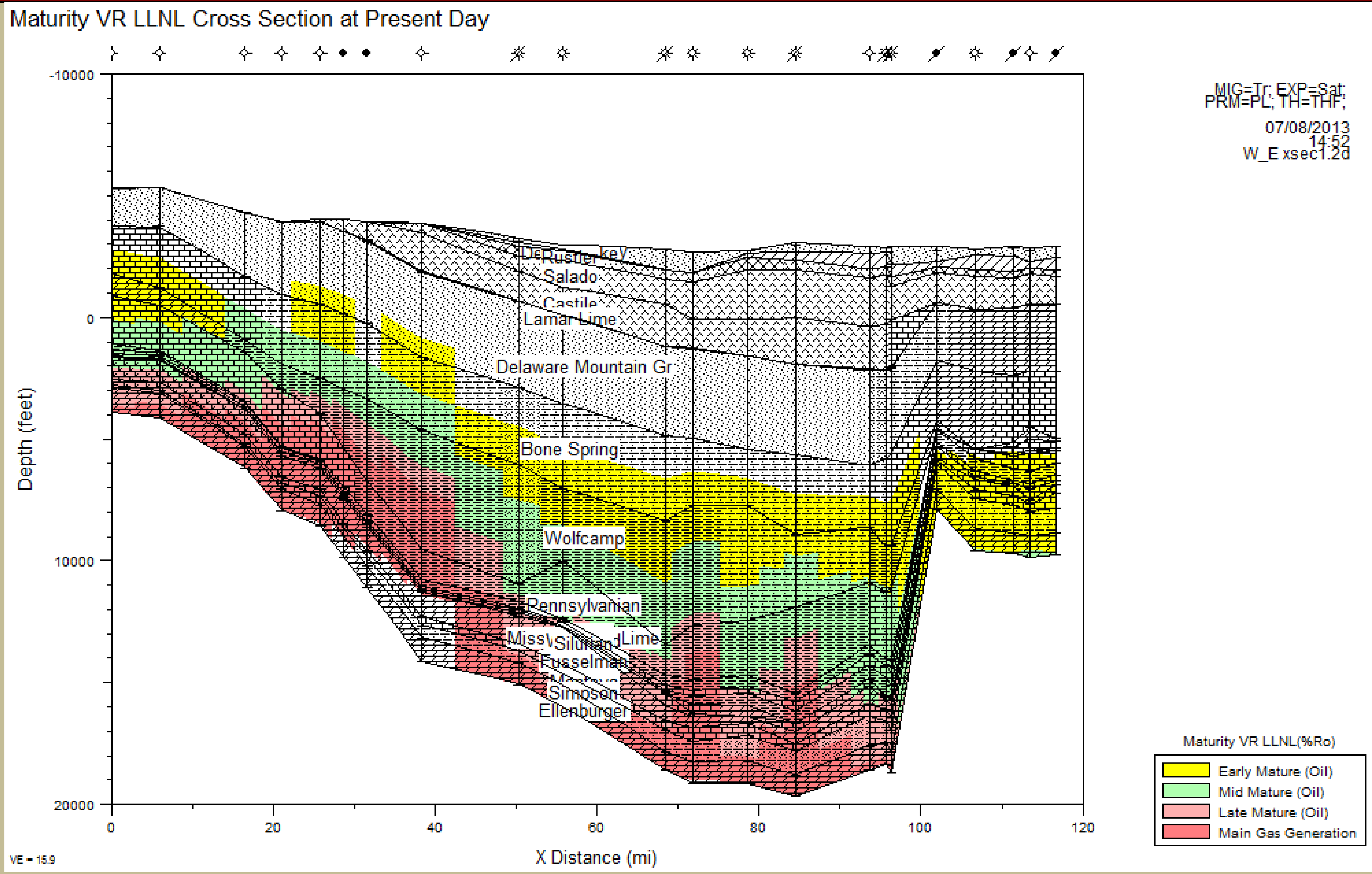


Epilogue

Basin comparison:

Though the two basins are separated in time and space and though they also differ in principal depositional environments (the dominantly clastic Mediterranean versus the dominantly carbonate Delaware basin):

- Both the late Miocene Mediterranean and the late Permian Delaware intracontinental seas became isolated when their major inlets to the world oceans pulsed in their restriction owing to tectonics (?) and eventually closed (the ancestral Strait of Gibraltar and the Hovie Channel, respectively).
- As a result, with restriction and eventual cut-off, both basins became increasingly anoxic and saline, with organic rich sediments culminating in extensive evaporates (the Messinian and Ochoan Castille evaporates, respectively).
- Both have high unconventional reserves (potential shales of the Mediterranean: Spathopoulos and Sephton, 2013; and the proven and presently produced shales of the Permian Basin).

Epilogue

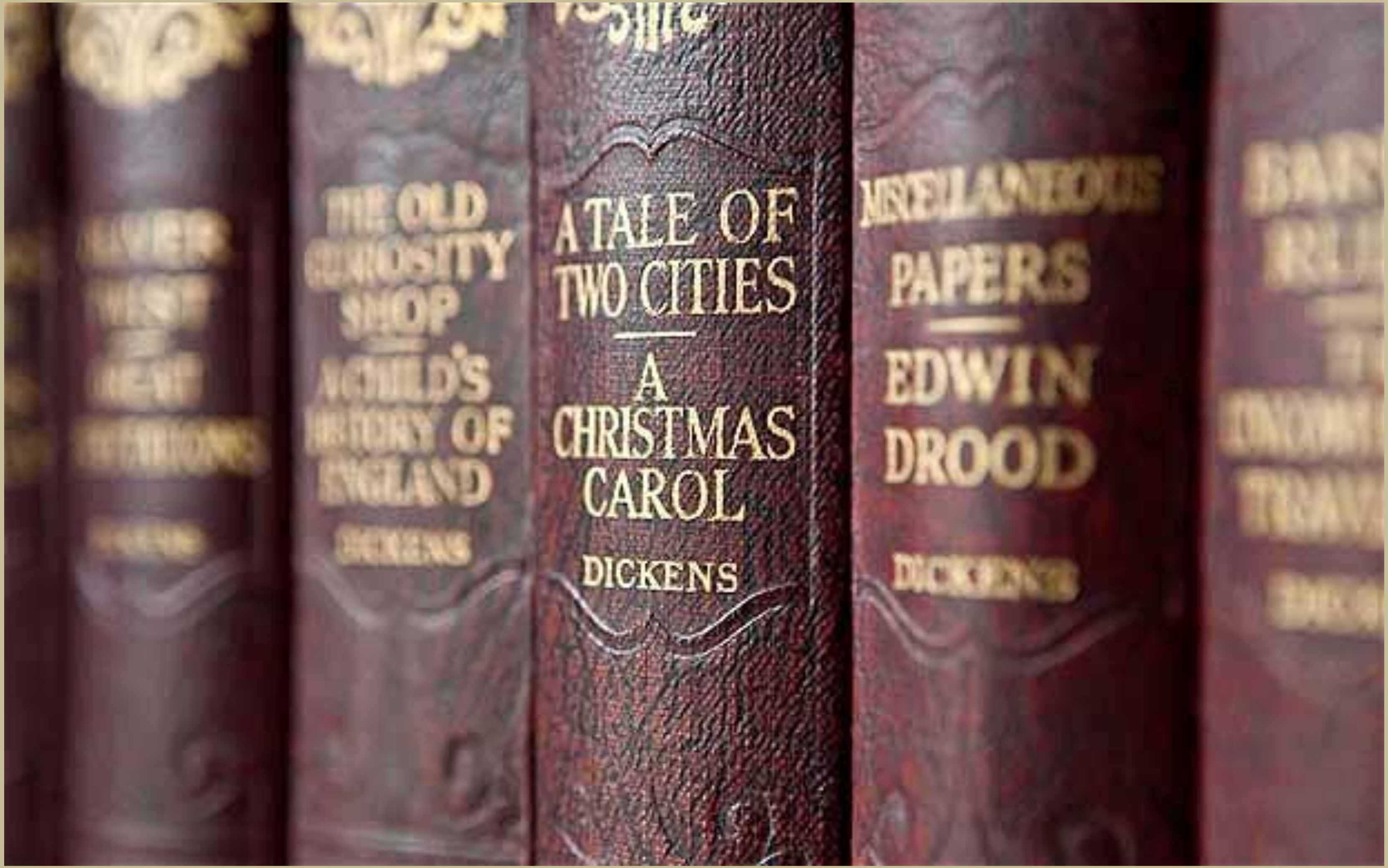
- Both the Messinian and Delaware basin salts exhibit a general West to East “Usiglio” lateral trend suggesting basin restriction, evaporation, and ocean influx from the West.
- While the Messinian has a SL curve which is antithetic to the global one, mysteriously the Permian basin coincides owing to Tectonic uplift of Pangea(?).
- During evaporation, both basins exhibited bathymetrically controlled pockets of anoxia which provided a heterogeneous basin distribution of preserved organic source rock richness.
- As salt conductivities are high, venting of heat allows sub-salt oil windows to be deeper than in adjacent non-salt regions of similar heat flows.
- While exploration on the periphery of the Mediterranean continues to focus upon the effects of the Messinian crisis upon fluvial systems within incised valleys sealed by transgressive fills, are there clastic analogs along the Delaware shelf edge?

Epilogue

- The Mediterranean has a lumpy bottom with anoxic sub-basins which focused organic deposition and preservation during restriction pulses. Might a similar spatial and temporal heterogeneity in source rock richness be exhibited in the poorly seismically imaged Delaware Basin basement floor?
- Post Messinian tectonics have led to discoveries in the Eastern Mediterranean, e.g. the Levantine Basin by Noble Energy. Could deciphering the strain history and structuring of the post Permian Delaware similarly lead to new exploration ideas, especially in the East?
- For the Mediterranean, can the Delaware conventional and nonconventional play concepts be used on the onshore basins peripheral to the Mediterranean (e.g. Western Desert of Egypt) following 3D basin modeling which designates migration pathways?
- Could there be high energy prospective reservoir sands associated with the Strait of Gibraltar Messinian Zanclean Flood and Hovie Channel influxes during Permian global sea level oscillations?
- Do other evaporite basins of the world have similarities to these two?

Coda: Many more books to read!

Each basin in the world is different. However, there are reoccurring common themes in their petroleum system evolution. These themes emerge, however, only after the generation of hypothesis, model construction, testing, and verification. And it is the analysis and testing of these theme models which provides not just insight but raises new questions.



Thank You

Acknowledgements

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