The Messinian evaporites in the Levant Basin: lithology, deformation and its evolution

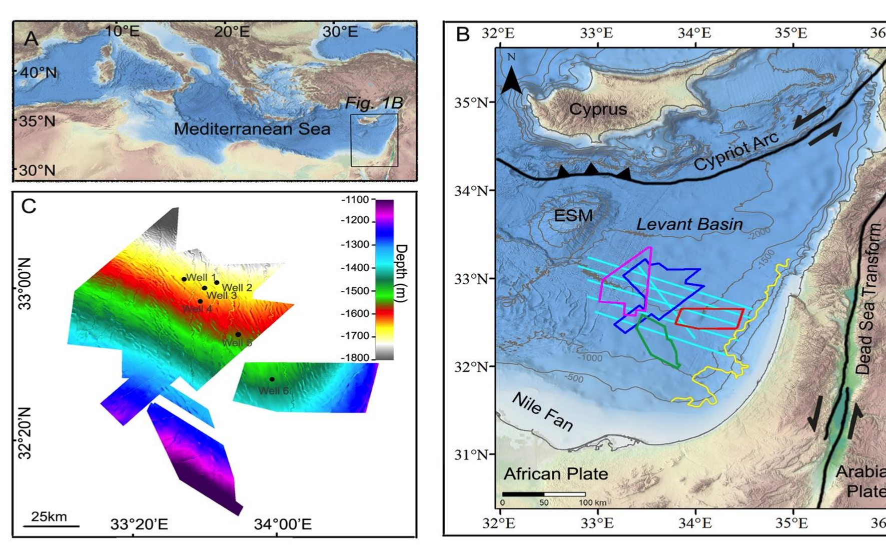
Ye E. Feng[1], Josh Steinberg[2], Moshe Reshef[1]
[1]Department of Geosciences, Tel Aviv University, Tel Aviv, Israel; [2]Ratio Oil Exploration, Tel Aviv, Israel
Email: yefeng@post.tau.ac.il

1. Introduction

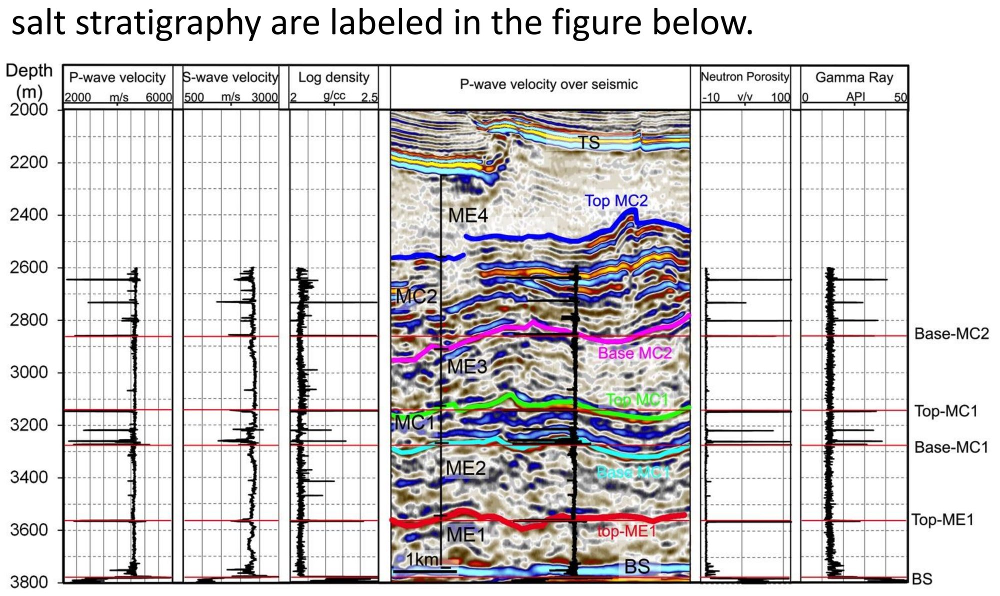
The motivation of this study is based on the simple fact that recent-discovered hydrocarbon reservoirs in the Levant Basin are situated underneath a thick layer of evaporites, which was deposited during the Messinian Salinity Crisis (MSC). For productive and safe drilling, it is crucial to fully understand the behavior of this massive salt sequence, since it can influence a hydrocarbon system at all aspects. However, the lithological composition of the Messinian evaporite in the Levant Basin remains controversial and salt deformation mechanisms are still not fully understood, due to the lack of high resolution 3D depth seismic data and well logs that record the entire evaporite sequence. In this study, by using 3D PSDM seismic data with great coverage and deepwater well log data from recently drilled boreholes, we aim to 1) reveal the lithology of the entire evaporite sequence; 2) to determine the intra-salt deformation mechanisms; and 3) to establish an evolutionary model of the Messinian evaporites in the Levant Basin.

2. Study area and dataset

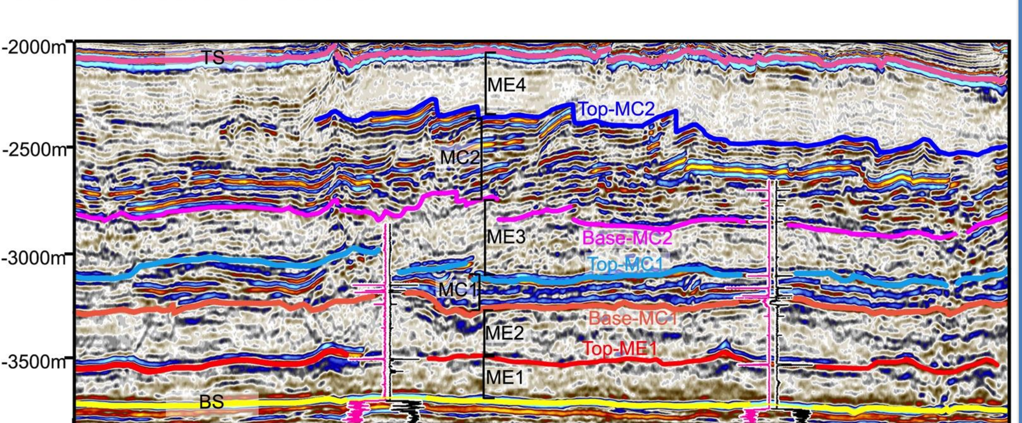
Our study area covers an extending area of ~18,000 km^2 in the Levant Basin, which is located in the easternmost Mediterranean basin. The dataset used in this study include four 3D PSDM seismic cubes and six 2D seismic lines. We have also obtained well logs from six recently-drilled industrial boreholes which penetrated the entire Messinian section.



A typical log suite consists of P- and S-wave velocities, log density, Neutron Porosity and Gamma Ray logs. The logs are tied well to the seismic, and log responses are coherent at different locations. Nomenclatures used to describe the intra-salt stratigraphy are labeled in the figure below.



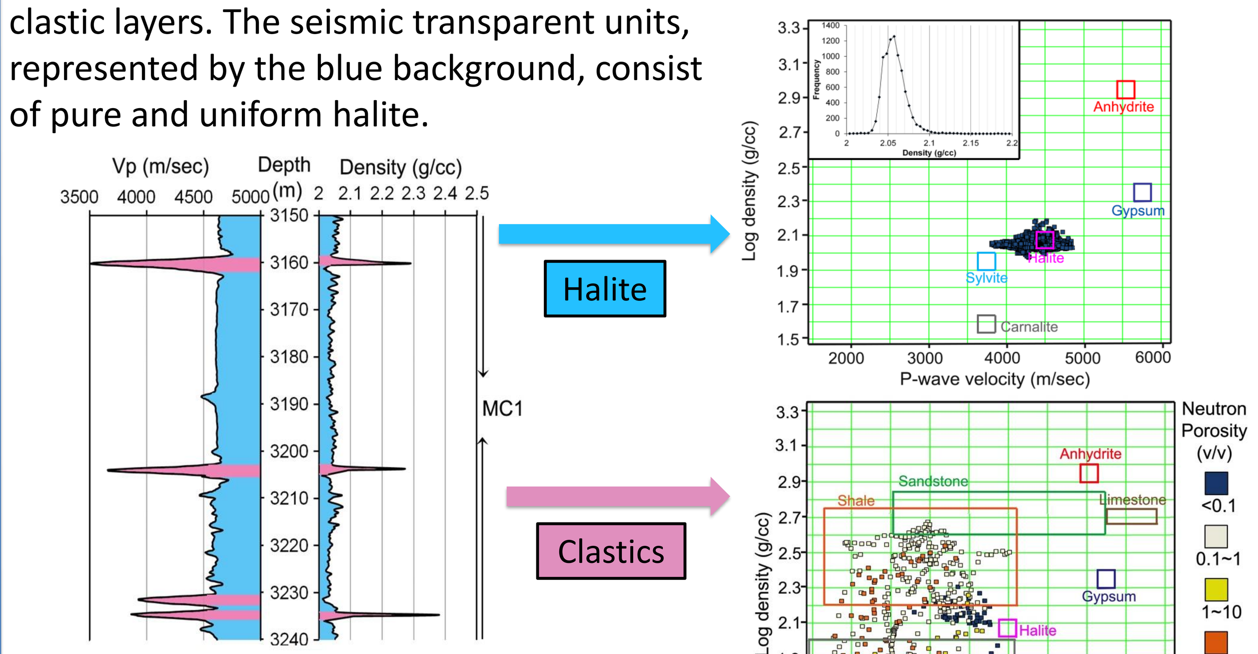
Note how P- and S-wave velocities show abrupt decreases while density, porosity and Gamma ray logs show drastic increases at the intra-salt reflectors.

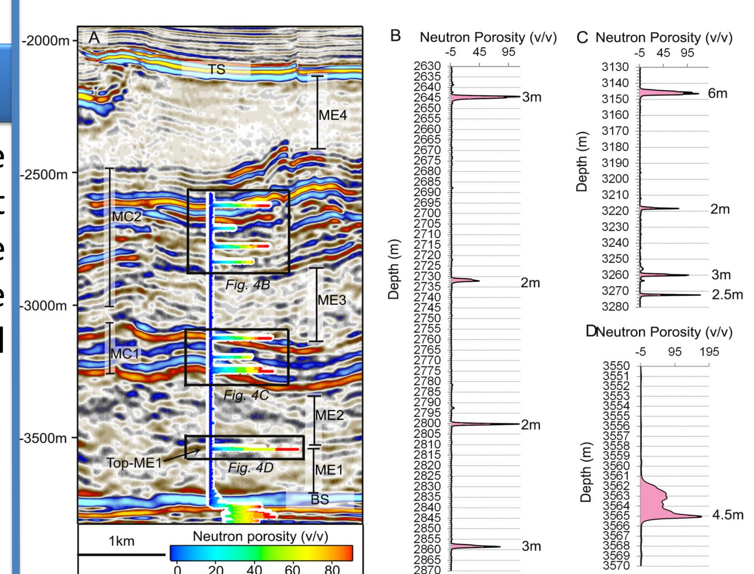


Neutron Porosity and P-wave slowness logs over seismic. Note how logs response to the intra-salt reflectors. Neutron porosity log shows positive/increase to the left.

3. Lithology of the evaporite sequence

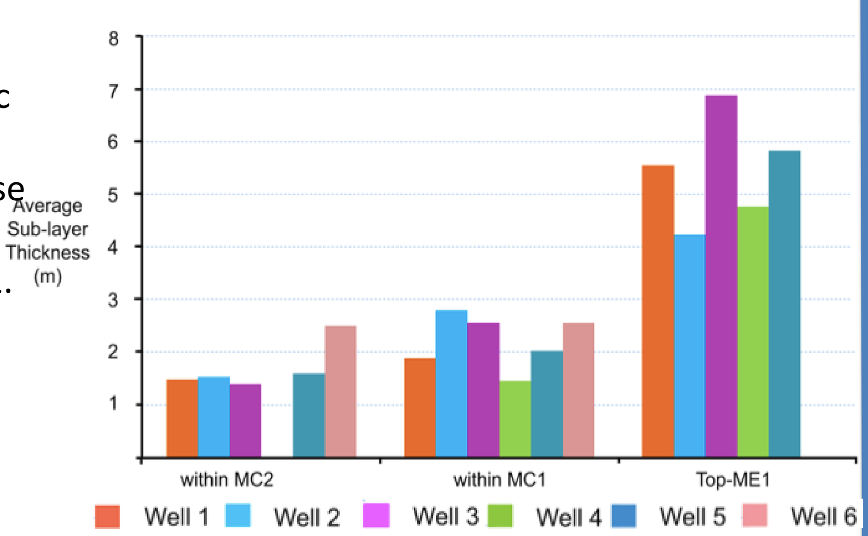
We separated all the Vp and density log responses (spikes) from six wells and plotted them onto two Vp-density crossplots. The results show that the spikes (pink), which represent the intra-salt reflective units, are associated with thin clastic layers. The seismic transparent units, represented by the blue background, consist of pure and uniform halite.

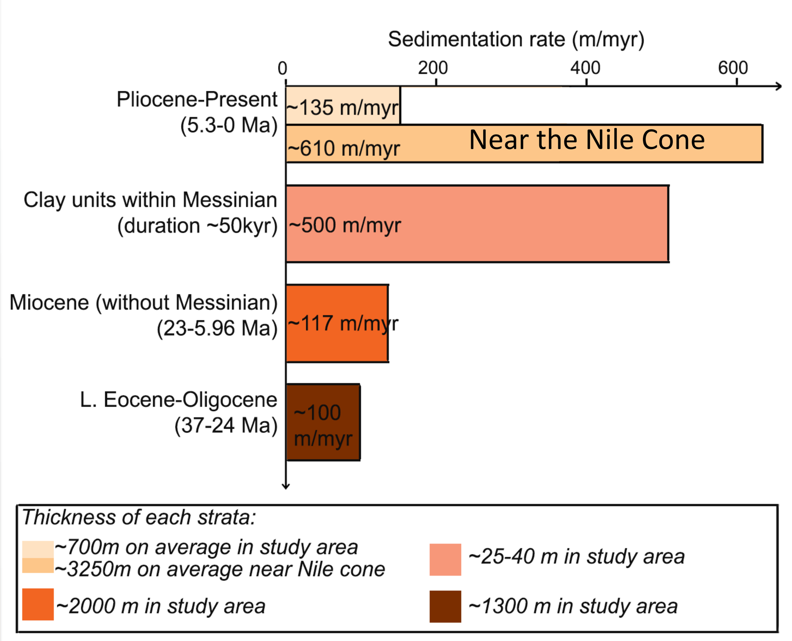




The thickness of these thin clastic layers can be easily measured from the well logs: they are about a few meters thick, with a total cumulative thickness of ~25 m throughout the evaporite sequence.

We then calculated the thickness of all the clastic layers and obtained the average thickness of these thin clastic layers within MC2, MC1, and Top-ME1. The result shows the average thickness of clastic layers increases from shallow to deep.

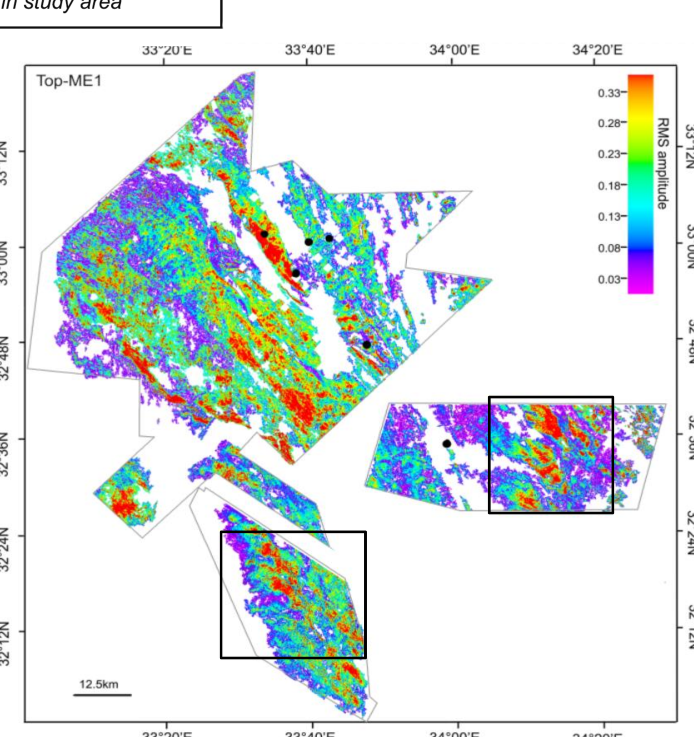




How did 25 m thick clastics deposit throughout the Levant Basin during the short MSC, as previous studies suggested the real evaporite deposition time during the MSC to be ~50 kyr or shorter. We calculated the clastic sedimentation rate and compared it to the pre- and post-Messinian sedimentation rate.

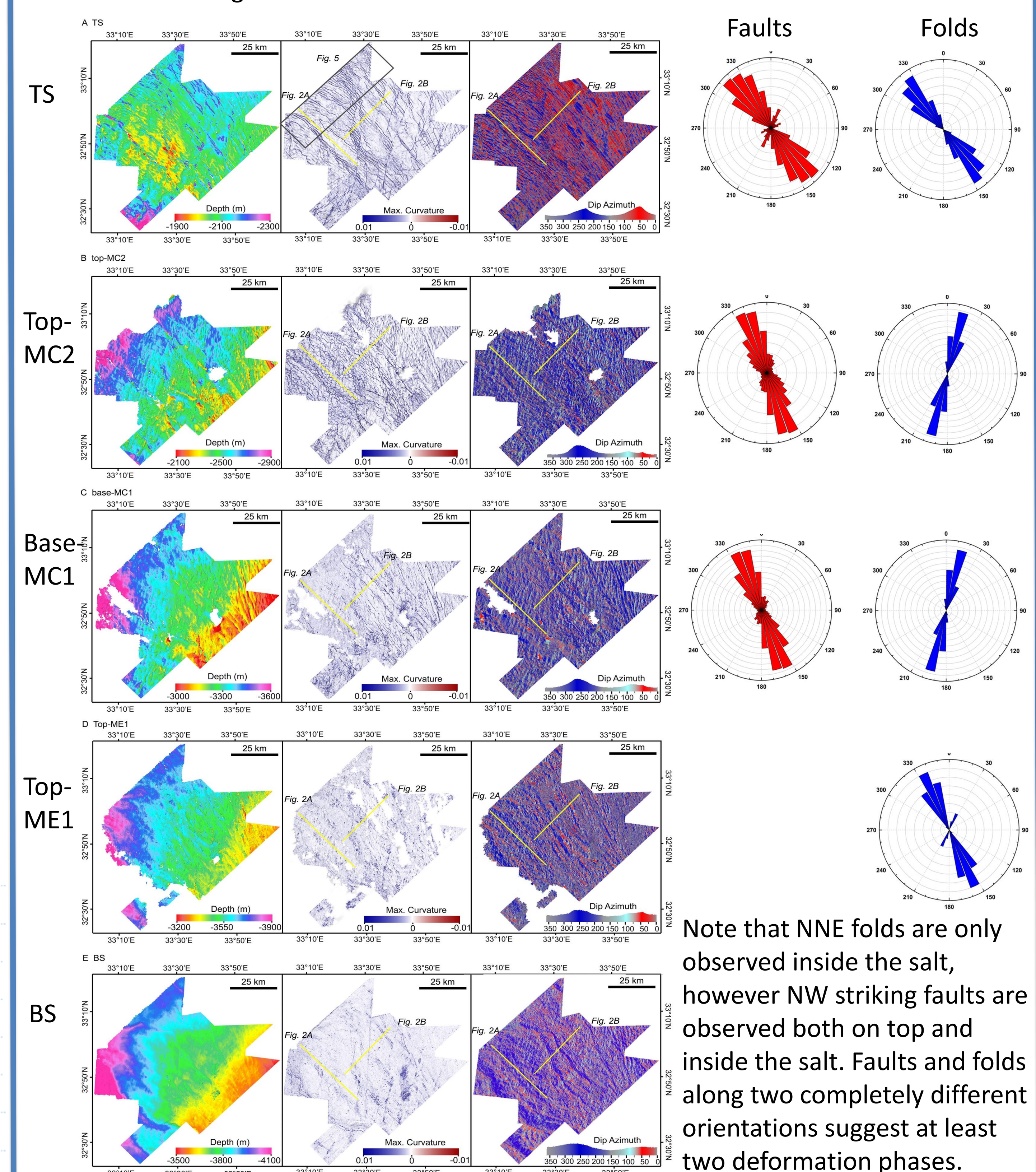
This extremely fast sedimentation rate suggests that the clastics may have been transported into the basin instead of in-situ deposition.

Moreover, some high amplitude fan structures are observed on the intra-salt units, widening towards the NW. These structures may further suggest the origin of the clastic materials inside the evaporite sequence.



4. Intra-salt deformation features and mechanisms

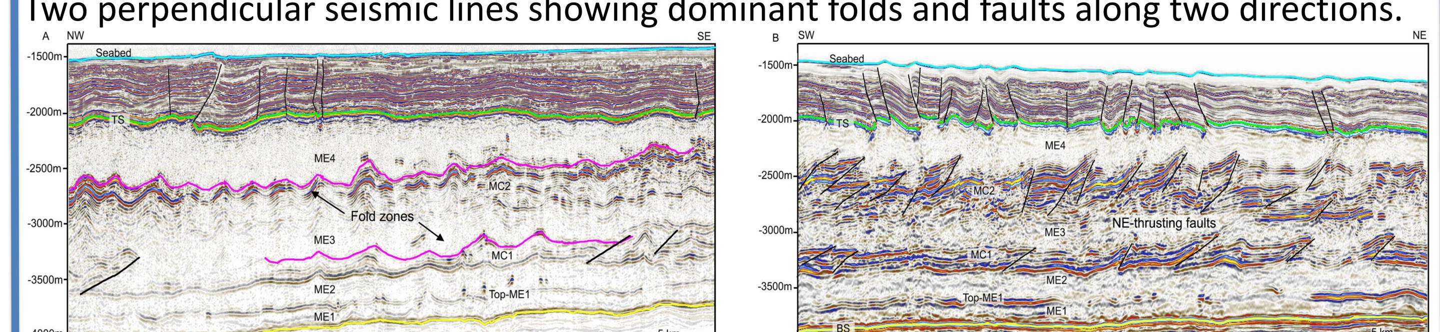
Since the intra-salt units are so intensely deformed that faults and folds are hard to observe on structural maps, we used maximum curvature and dip azimuth attributes to highlight intra-salt faults and folds. Then we picked all these faults and folds and plotted them onto rose diagrams.



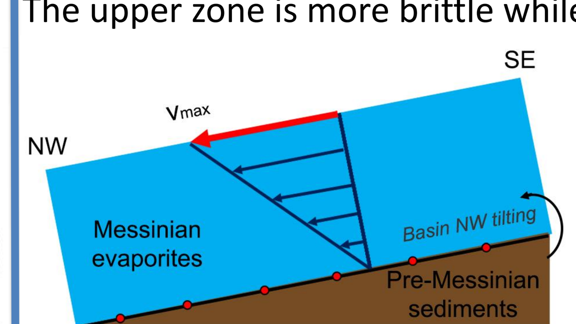
Note that NNE folds are only observed inside the salt, however NW striking faults are observed both on top and inside the salt. Faults and folds along two completely different orientations suggest at least two deformation phases.

Deformation phase	Evidence	Mechanisms
Syn-depositional	NNE folds only observed on the intra-salt units	Basin NW tilting after the MC2 formation but before TS formation
Post-depositional	NW striking faults observed both on top and inside salt	Nile Delta spreading during the post-Messinian

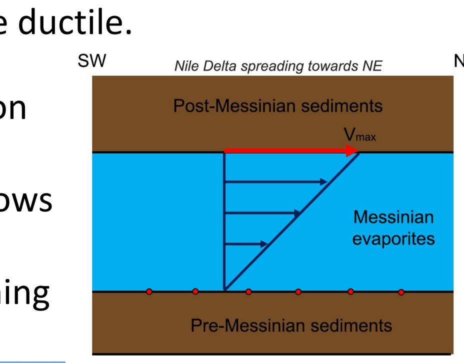
Two perpendicular seismic lines showing dominant folds and faults along two directions.



The upper zone is more brittle while the lower zone is more ductile.

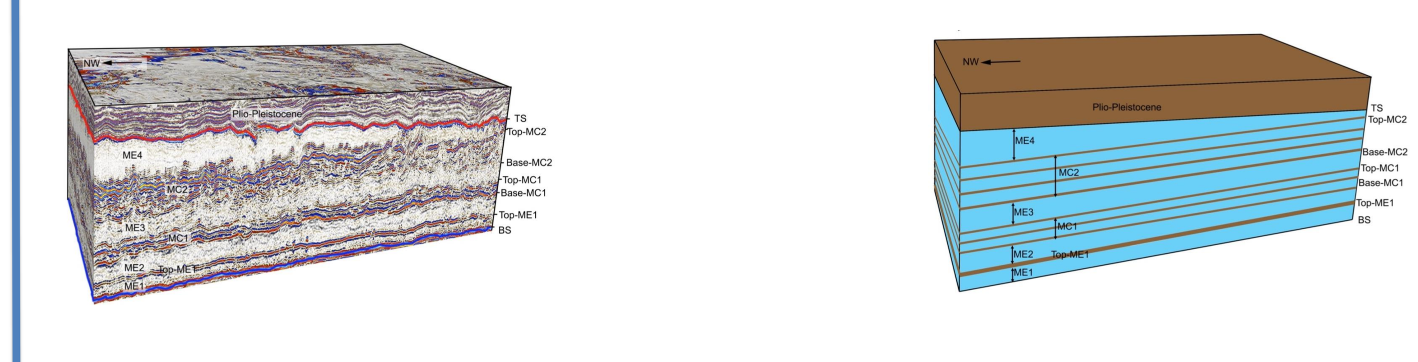


Under both deformation phases, salt follows Couette flow which shows max. velocity at the uppermost unit, matching our observations.

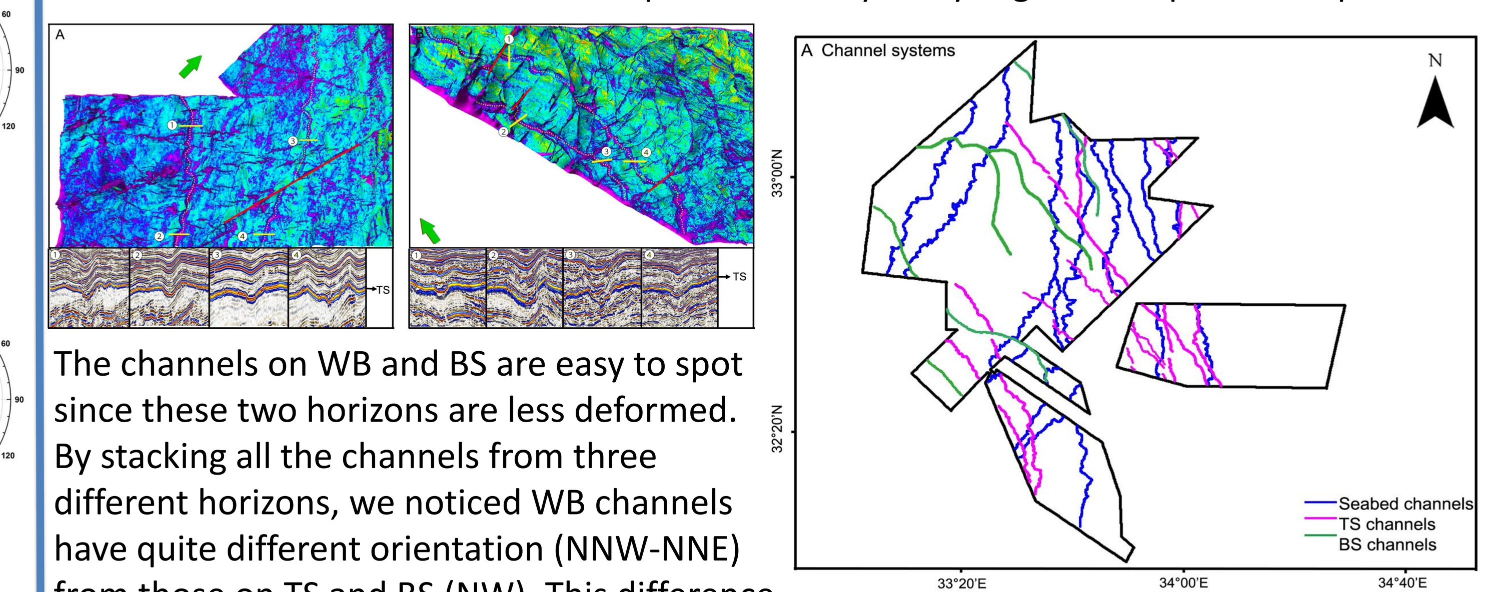


5. Evolution model of the evaporites in the Levant Basin

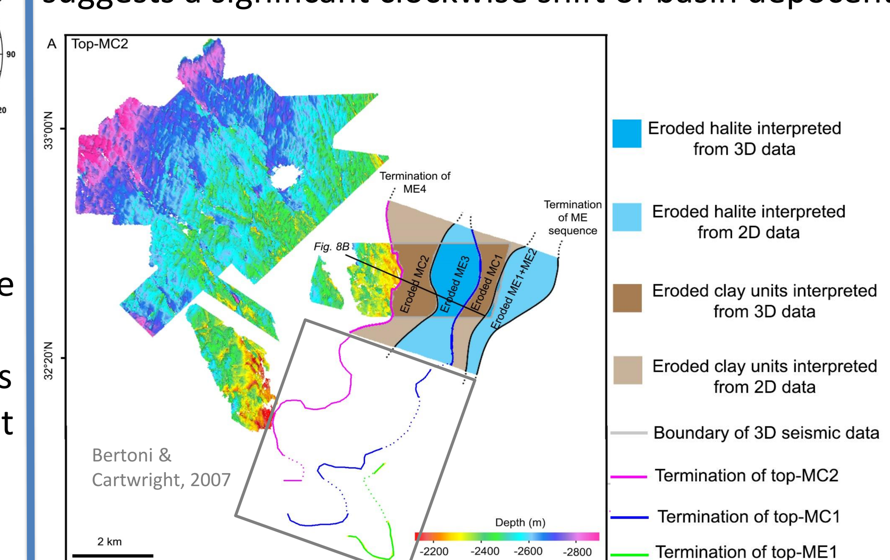
We generated a series of depth structural maps and thickness maps of the intra-salt units, which show the geometry of the Messinian evaporite layer in the Levant Basin: a regionally horizontal TS reflector overlying NW-dipping intra-salt reflectors, and a NW-thickening uppermost ME4 unit overlying all the other intra-salt units with generally uniform thickness.



We have also observed channels on top of the salt by analyzing RMS amplitude maps of TS.

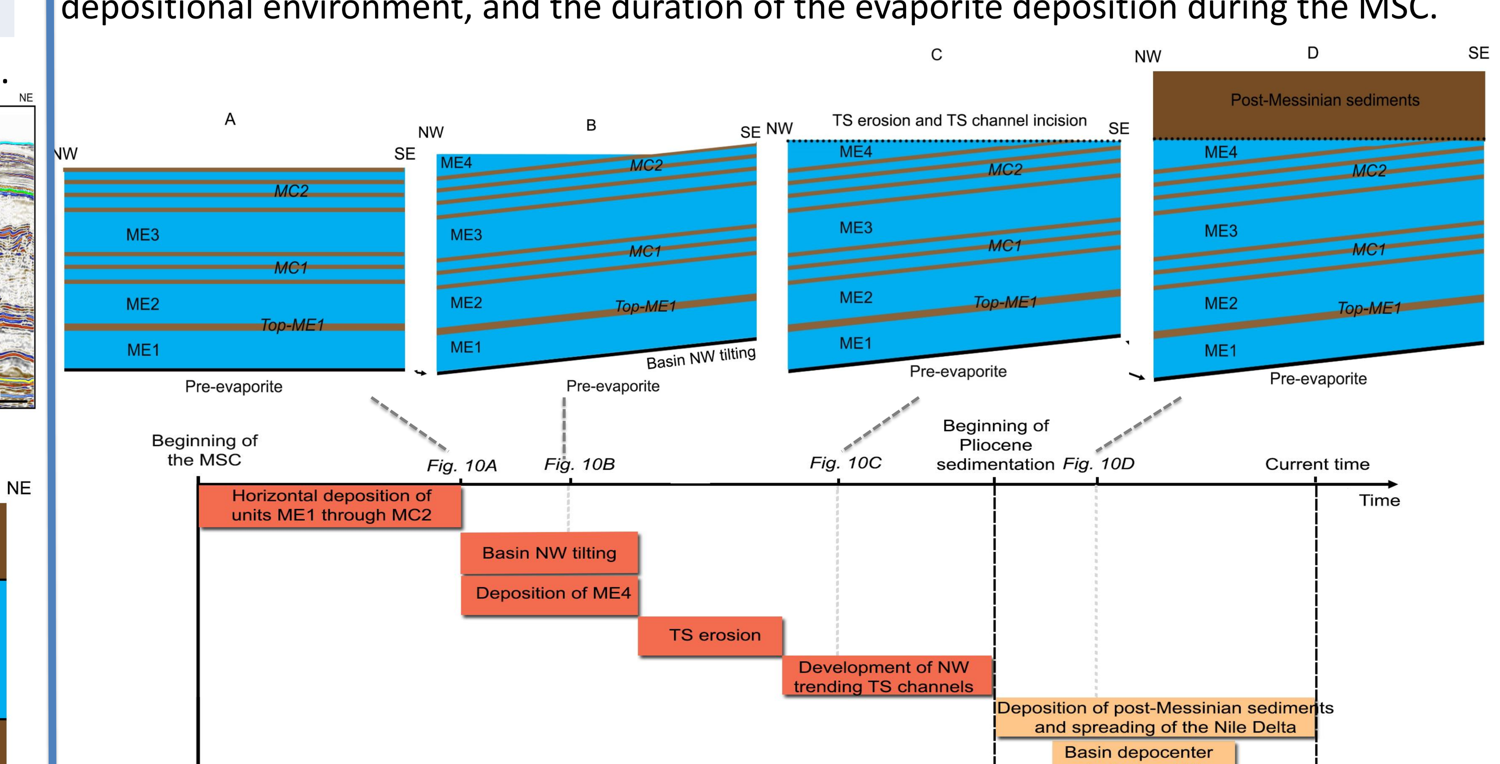


The channels on WB and BS are easy to spot since these two horizons are less deformed. By stacking all the channels from three different horizons, we noticed WB channels have quite different orientation (NNW-NNE) from those on TS and BS (NW). This difference suggests a significant clockwise shift of basin depocenter between the TS and WB formation.



TS erosion is also observed in the proximal area, where truncation of intra-salt against TS can be seen. From both 3D and 2D seismic data, the mapped erosional area shows NE-elongated stripes, suggesting when erosion occurred all the intra-salt units were already dipping to the NW.

By combining all our observations and interpretations on the geometry of the evaporites and the intra-salt deformation features, we established an evolutionary model of the Messinian evaporites in the Levant Basin. Fully understanding the origin of the clastic materials inside the salt can bring further information on the paleoclimate, the depositional environment, and the duration of the evaporite deposition during the MSC.



6. Summary

In this study, we for the first time revealed the lithology of the entire Messinian evaporite sequence in the Levant Basin to be thin clastic layers interbedded in pure and uniform halite background. We also report for the first time channelized systems on top of the evaporites, the flow direction of which indicates a significant clockwise shift of basin depocenter. Intra-salt faults and folds are analyzed using different seismic attributes, suggesting a two-phase deformation theory including a basin NW tilting as syn-depositional phase and the Nile Delta spreading as the post-depositional phase. Finally, an evolutionary model of the evaporites in the Levant Basin is established. Fully understanding the origin of these clastics inside the evaporites can help further decipher the paleoclimate and the depositional environment during the MSC.

ACKNOWLEDGEMENT: The authors would like to thank Ratio Oil Exploration, Noble Energy, Delek Energy, Avner Oil Exploration, Modiin Energy, ILDC Energy, Pelagic partnership and Edison International S.p.A. for kindly providing the data and permission to publish. We would also like to thank EMODnet Bathymetry portal for providing the bathymetric metadata.

References:

Ben-Avraham et al. (2002). Crustal structure of the Levant Basin, eastern Mediterranean. Tectonophysics, 346(1–2).
Bertoni, C., & Cartwright, J. A. (2007). Major erosion at the end of the Messinian Salinity Crisis: evidence from the Levant Basin, Eastern Mediterranean. Basin Research, 19(1), 1-18.
Gvirtzman et al. (2013). Intense salt deformation in the Levant Basin in the middle of the Messinian Salinity Crisis. Earth and Planetary Science Letters, 379, 108-119.
Hübscher et al. (2009). Salt tectonics and mud volcanism in the Latakia and Cyprus Basins, eastern Mediterranean. Tectonophysics, 470(1–2), 173-182.
Hsu et al. (1977). History of the Mediterranean salinity crisis. Nature, 267(5610), 399-403
Lofi et al .(2011). Refining our knowledge of the Messinian salinity crisis records in the offshore domain through multi-site seismic analysis. Bulletin de la Societe Geologique de France, 182(2), 163-180.
Netzeband et al. (2006). The structural evolution of the Messinian evaporites in the Levantine Basin. Marine Geology, 230(3–4), 249-273.
Reiche et al. (2014). Fault-controlled evaporite deformation in the Levant Basin, Eastern Mediterranean. Marine Geology, 354, 53-68.
Weijermars, R., & Jackson, M. P. A. (2014). Predicting the depth of viscous stress peaks in moving salt sheets: Conceptual framework and implications for drilling. *Aapg Bulletin, 98*(5), 911-945.