Improved imaging of Late Miocene (Messinian) to Plio-Quaternary units in the Algero-Balearic basin

Simon Blondel[1,2], Angelo Camerlenghi[1], Anna Del Ben[2], Fadl Raad[3], Johanna Lofi[3]

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ABSTRACT

This study aims to contribute to the understanding of the Mediterranean Salt Giant in the Western Mediterranean, formed about 6 Ma ago during the Messinian Salinity Crisis (Hsü et al., 1973). Here we reprocess multichannel seismic reflection data with the aim of improving our knowledge of the stratigraphy in the Algero-Balearic deepwater basin and its continental margins, in the absence of lithological information from wells.

We investigate the seismic expression of the Messinian Salinity Crisis from the south-east of the Balearic promontory to the central Algero-Balearic abyssal basin and the associated salt tectonics. Here the segmentation of salt structures has been previously described using shallow chirp sonar data, low-resolution vintage multi-channel seismic data and high-resolution multi-channel seismic data (Camerlenghi et al., 2018; Dal Cin et al., 2016; Mocnik et al., 2014).

The structure of the northern Algero-Balearic basin is controlled by two abrupt fault scarps oriented SW–NE (mainly the Emile Baudot Escarpment transform fault) and WSW-ENE (mainly the Mazarron Escarpment transform fault) emplaced during the basin extension, and later intruded by steep and narrow volcanic ridges of Pleistocene age. It is a good analogue to early stage salt tectonics for older and more complex salt giants in the North Sea or the Gulf of Mexico.

We reprocessed 2D Kirchhoff PSTM multi-channel seismic data acquired by the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS (SBALDEEP Cruise of 2005 and SALTFLU cruise of 2012; the latter within a Eurofleet cruise) spanning the south east continental margin of the Balearic islands and the Algero-Balearic basin. The reprocessing was designed to improve the continuity of the reflectors by migrating with a Kirchhoff PreSTM using a detailed velocity model, while preserving amplitude information. The objectives are to better image the structural complexity of the area and to analyse the amplitude variation within the Messinian units, in an attempt to derive the composition of the salt and the pore pressure regime.

We present preliminary results where we evaluate the presence of the Messinian Trilogy in the south-eastern continental slope. We attempt to reconstitute the paleo-depositional environment of the various depositional units, and the effect of crustal structures and salt tectonic gravity spreading and gliding on their syn- to post-depositional evolution. Finally, we search for evidence of fluid circulation within the Messinian and the Plio-Quaternary deposits in the study area.

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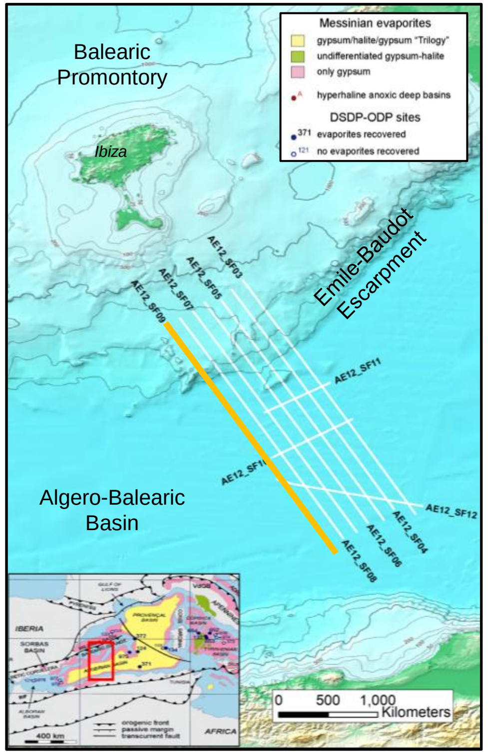
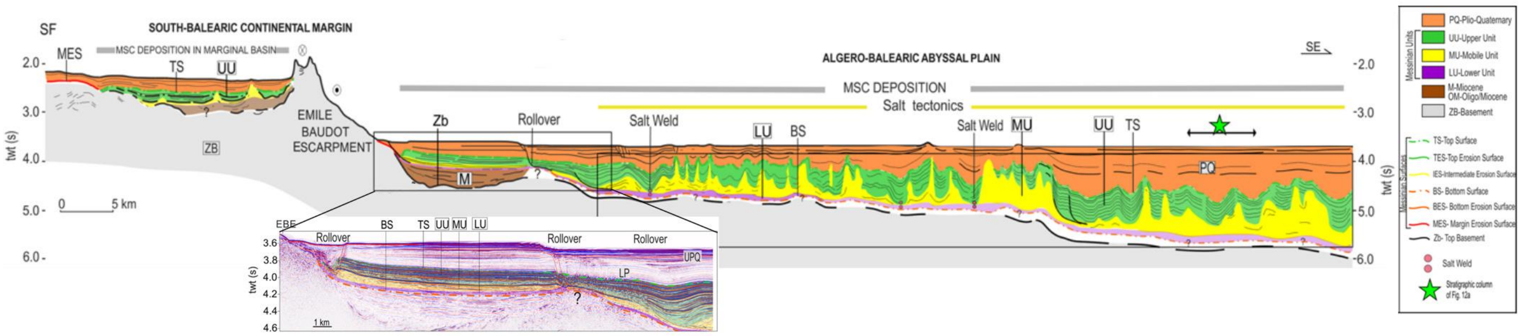
One of our objectives is to develop a mechanistic and quantitative understanding of early salt deformation and sub-salt overpressure development to mitigate the risks associated with drilling in salt-capped hydrocarbon provinces.



Location of the SALTFLU dataset on the GEBCO bathymetric map. The location of the dataset is shown on a map of the Messinian seismic facies distribution from Roveri et al., (2014). The yellow line indicates the position of E12_SF09 line, of which the referenced interpretation is presented.



Interpretation of the pre-stack time migrated profile SALTFLU-09 (AE12_SF09) of the south Balearic margin and adjacent northern Algero-Balearic abyssal plain (from Dal Cin et al., 2016). The Messinian Trilogy is present and thins toward the continental margins with onlapping terminations. Salt deforms and intrudes the overlying UU and Plio-Quaternary (PQ) sequences.

SETTINGS

- The field of study lies within the western Mediterranean Sea and covers the **transition from the Balearic Promontary to the oceanic Algero-Balearic back-arc basin** opened between ~26 and 8 Myrs ago (Mauffret et al., 2004).
- Previous studies have described an **Oligo-Miocene to Plio-Quaternary sediment cover**, recognizing the presence of Messinian units both on the Balearic promontory (Camerlenghi et al., 2018; Dal Cin et al., 2016; Driussi et al., 2015) and the Algero-Balearic basin (Camerlenghi et al., 2018; Dal Cin et al., 2016; Mocnik et al., 2014; Wardell et al., 2014; Caprone et al., 2011).
- Although **the presence of the Messinian Lower Unit (LU) is suspected** further south and east (Capron et al.,2011; Medaouri et al., 2014), it has not been yet proven here because the base of the salt and the sub-salt were not clearly imaged on the vintage imaging project
- The **presence of the Messinian seismic facies on this part of the Balearic promontory must be verified** because of the vicinity of important volcanic structures. Dal Cin et al., 2016 suggested the presence of the Messinian Mobile (MU) and Upper (UU) Units, while Driussi et al., (2014) and Camerlenghi et al., (2018) interpreted the presence of the Messinian Bedded Unit (BU) onlapping possible volcanic structures.
- Salt induced deformation of the Mobile salt Unit (MU) occurs south of a linear structure in the abyssal plain located some tens of kilometres from the base of the slope resulting **in complex and steep salt geometries, with several structures piercing at the seafloor** where the Plio-Quaternary cover is not too thick (Camerlenghi et al., 2009)
- The main parameters governing the **halokinetic processes vary with authors** (Dal cin et al., 2016; Mocnik et al., 2014; Wardell et al., 2014) **and are not yet well understood**
- Seismic amplitude anomalies and normal faults in the lower Pliocene and UU have been associated to the **presence of fluid circulation** within the Messinian sequence and favoured by heat flow contrasts (Camerlenghi et al., 2009; Poort et al., 2020). Alternatively, the normal faults in the lower Pliocene and UU could be related to the flow of the underlying salt instead of fluid migrations
- **The quality of the vintage time imaging was not enough to fully understand the geology of the area.**

We present new imaging aimed at providing better imaging of the subsalt deposits, by applying a state-of-the-art pre-processing flow and detailed velocity model building for time imaging.

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INPUT SEISMIC DATASET

The SALTFLU multi-channel seismic dataset consists of ten 2D profiles acquired in 2012 by the OGS Explora within Eurofleets Project SALTFLU. The source was made of two arrays of four GI-guns towed at 3 meters depth and a shot interval of 25 meters. The receiver array consisted of a single 3km length streamer of 240 channels, spaced at 12.5 meters interval, with a near-offset of 100 meters away from the boat and towed 4 meters below the surface. The sample interval was 2ms.

METHODS

- The **previous project did not include enhancement and preservation of low-frequency signal**, and the velocity field was built on a **coarse stacking velocity field**. The new processing flow has been elaborated to:
  - Improve the imaging of Messinian units in time and depth
  - Image pre-salt reflectors
  - better assess lithological and petrophysical properties of the subsurface
- The main challenges are to:
  - attenuate strong swell noise without filtering low-frequency primary signal
  - recover low-frequency content of the signal
  - remove an inconsistent bubble from the dataset
  - estimate a source signature to perform a single-operator deterministic amplitude-preserving deconvolution as a designature
  - Filter interbed multiples and out-of plane reflections
  - Estimate a reliable velocity field of a highly deformed and salt giant with a short offset (3km) dataset, ideally accounting for varying interval velocity for salt bodies

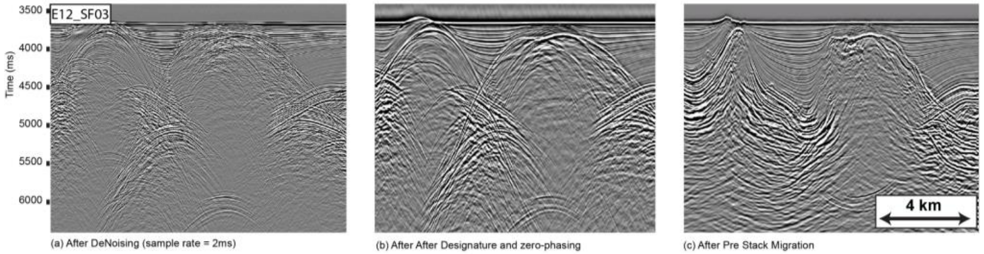
The processing has been performed using REVEAL © from Shearwater GeoServices.

- The new processing flow is designed using state of the art marine processing techniques used in the energy industry including: swell and linear noise attenuation, deghosting, de-bubble, designature. The initial velocity model is built through several iteration of semblance based migration velocity analysis (with a pre-stack Kirchhoff time migration, and Radon interbed multiple attenuation).
- The resulting images after pre-processing display an improved signal bandwidth needed to image deeper subsalt sediments.
- Future work consists of improved elimination of peg leg multiples and refining the velocity model in depth through several iterations of conventional tomography and pre-stack Kirchhoff depth migration.

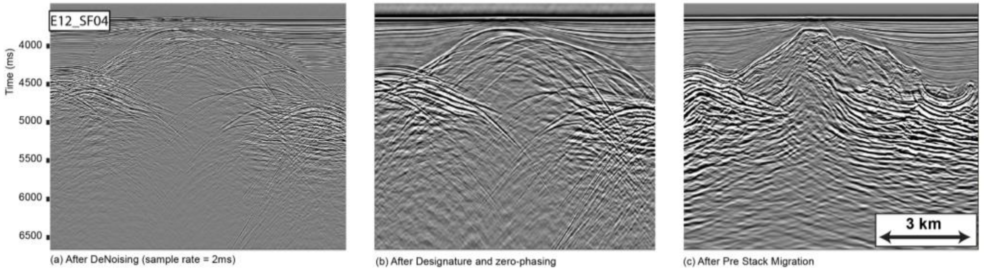
Processing workflow designed for the SALTFLU time imaging project

1. Data Loading
2. Geometry Loading
3. Recording delay shift statics
4. Resample from 2ms to 4 ms
5. Swell Noise removal
6. Trace Edit
7. Deghosting
8. Estimate signature from water bottom
9. Designature and zero-phase conversion
10. Tau-P Noise attenuation
11. 3km velocity analysis
12. Phase Inverse Q
13. Offset regularization
14. Kirchhoff PSTM
15. Radon Demultiple 1
16. 1.5 km Kirchhoff PSTM velocity analysis
17. Final Kirchhoff PSTM
18. Radon Demultiple 2
19. 50m Autopicked Residual Moveout analysis
20. Residual Noise Attenuation
21. Stack
22. Post stack refinements and scaling

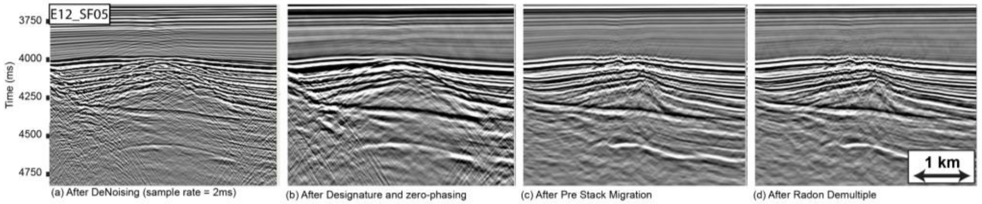
PSTM SEG-Y output in Time



Part of stacked sections of line E12_SF03 through the different processing steps. Bandwidth enhancement using deghosting, water-bottom derived designature and zero-phasing allow to effectively boost the low-frequency content of the data. The base of the salt structure appears more clearly



Part of stacked sections of line E12_SF04 through the different processing steps. A 3km interval picking grid has improved the results of migration, revealing reflections below the salt. Further work to remove out-of plane reflections and, more importantly, pre-stack depth migration will improve the output images



Part of stacked sections of line E12_SF05 through the different processing steps. Locally, peg-leg multiples are hiding the signal below the salt unit. A first attempt to filter them in Radon domain by exploiting their move-out difference does not remove them completely (notice the residual peg leg of top-salt) because their velocity is too close to the primary signal.

We would like to thank Shearwater GeoServices for providing an academic licence for the Reveal software used in this study

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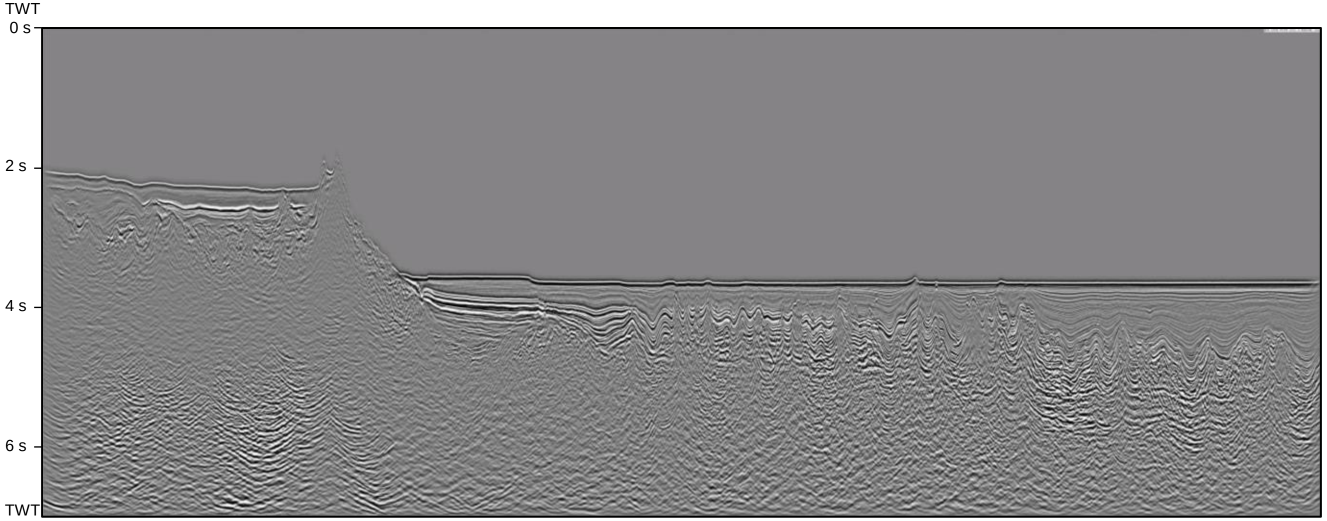
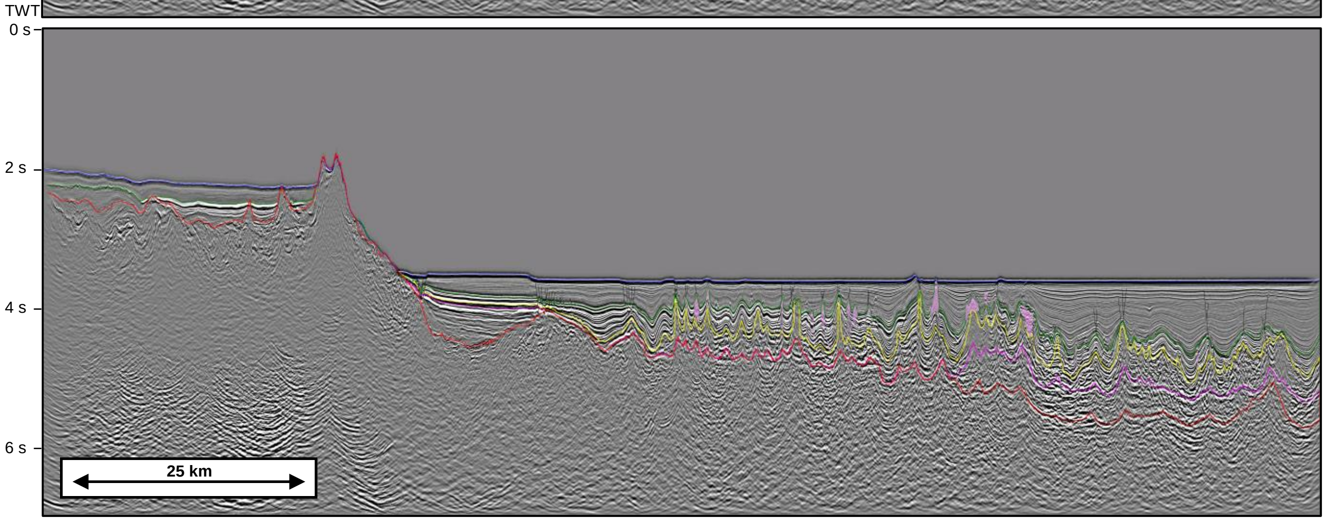
RESULTS

We present a preliminary revised interpretations of the Pre-Stack Migrated seismic line E12_SF09.





Base Volcanics and Messinian — Top Autochtonous Salt — Water bottom

Base Autochtonous Salt — Base Overburden — Allochtonous salt

New interpretation of the Pre-stack Migrated profile SALTFLU-09 (AE12_SF09). The new images display a better resolution of the salt structures edges and new reflectors below the salt. New interpreted thickness suggest a thicker Messinian upper Unit, a much thinner Mobile Unit, and a possibly thicker Lower Unit at the center of the Algero-Balearic abyssal plain. The interpreted horizons will be used to build the initial model for depth processing. Vertical exaggeration x4.

We propose a new interpretation suggesting that:

- MU seems thinner and more deformed than previously interpreted (Dal Cin et al., 2016; Mocnik et al., 2014), with pinched-off diapirs evidenced by secondary welds cross-cutting the overlying Upper Unit
- Thanks to the new processing strategy, a low amplitude and low frequency seismic unit beneath the Mobile unit appears clearly in the deepest part of the basin, with an average thickness of 0.3s TWT. It is hardly visible toward the margins. It is comparable to the LU described by Medaouri et al., (2014) at the transition from the Alboran to the Algero-Balearic basins.
- New images highlight the differences in seismic facies between the promontory and the deep basin. This leads us to prefer the interpretation from Camerlenghi et al., (2018), who describes the steep structures of the promontory as volcanic reliefs onlapped by BU, to the interpretation of diapirs of MU rising through the UU (Dal Cin et al., 2016). However, the presence of a thin salt layer lying below the BU cannot be excluded.
- We suggest that upper UU and the Plio-Quaternary cover are halokinetic sequences within mini-basins between rising salt structures. This is evidenced by internal unconformities, onlapping along the salt diapirs flanks and variable thickness of these units, with a maximum at the center of mini-basins.
- Folded and thrusted structures along inverted faults suggest an episode of shortening, upthrowing a previously deformed overburden along steepening flanks of the salt structures
- Further work will include a detailed study of UU and Plio-quaternary terminations to track the different episodes of halokinesis.

CONCLUSION

We were able to improve the image of the Algero-basin by performing bandwidth enhancement of the seismic data and velocity-model refinement. New images allow to better delimit the salt structures and the pre-salt topography. The salt appears thinner and more deformed than previous interpretations on vintage images. Salt structures display evidence of contractional salt tectonic, with folding and thrusting along inverted faults along salt rollers. Velocity model refinement and Pre-stack depth migration will allow further improvement of the images. Results will help in better understanding the paleo-environment during the end of the Messinian Salinity crisis within the Algero-Balearic basin.

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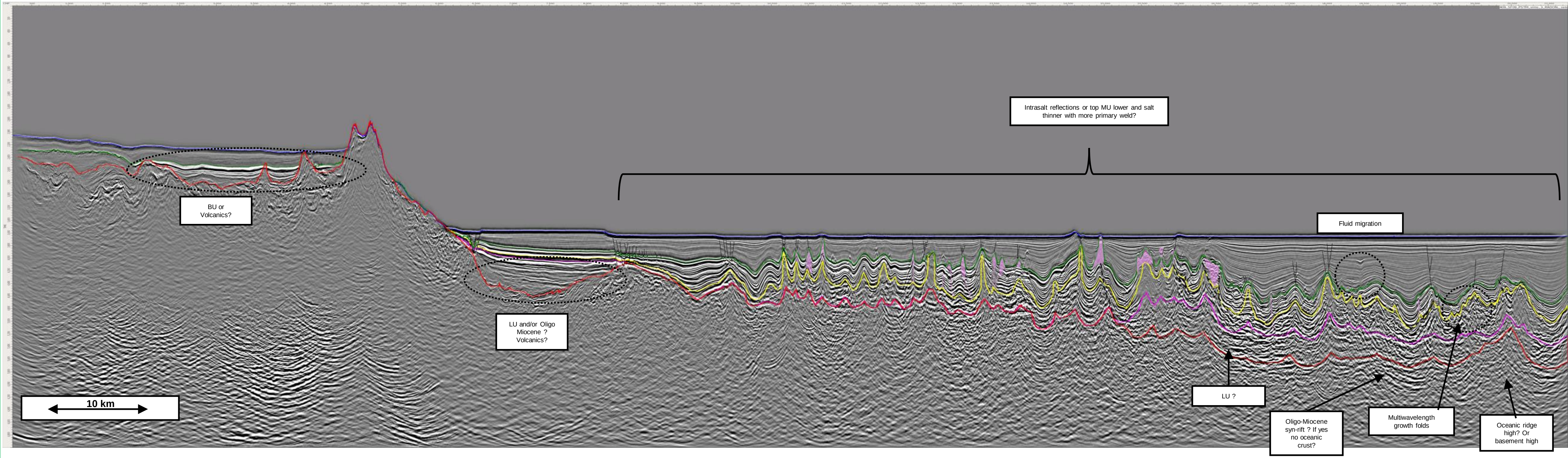

Base Volcanics and Messinian — Top Autochtonous Salt — Water bottom — Faults — Secondary weld

Base Autochtonous Salt — Base Overburden — Allochtonous salt — Inferred inverted thrust

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