Integration of marine geology of the Strait of Gibraltar with paleostress history of the Tangier peninsula, Morocco: implications for the Messinian Gibraltar corridor

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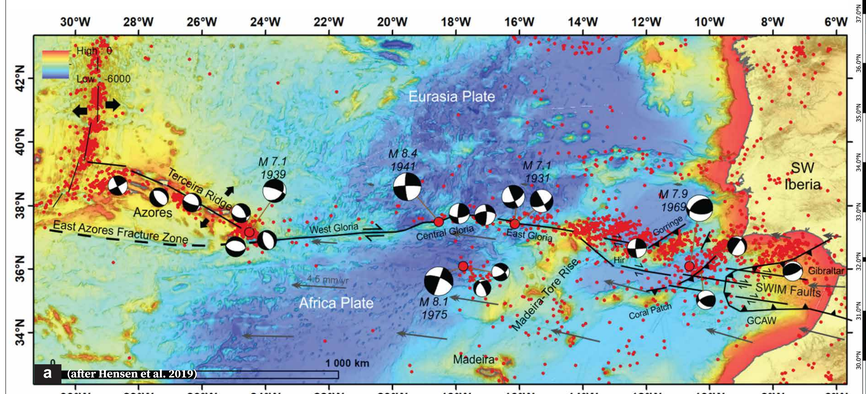
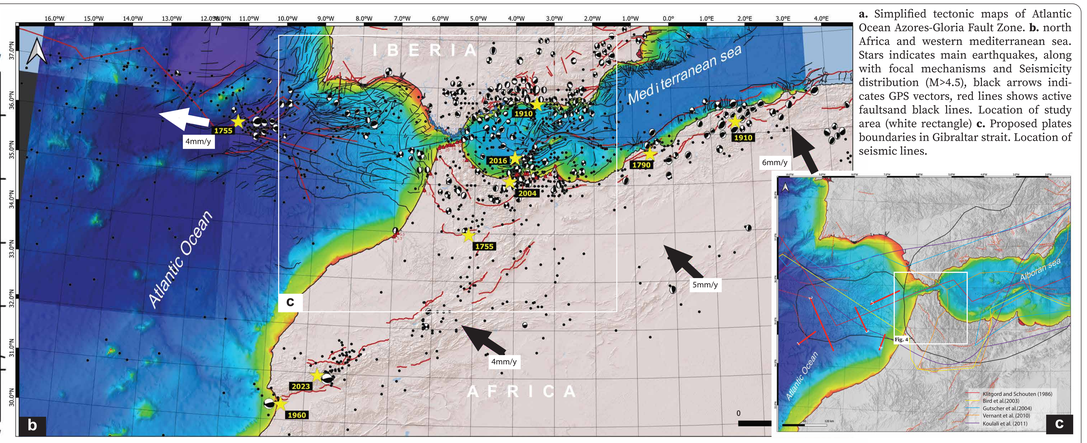
ABSTRACT

Previous workers have used stratigraphic studies to identify three potential marine gateways that connected the Atlantic and Mediterranean during the Messinian salinity crisis (MSC): the Strait of Gibraltar that remains a 300-900-m-deep channel to the present-day and the Betic and Rifian corridors now exposed onland in southern Spain and northern Morocco, respectively. Comparison of deepsea cores from the Atlantic and Mediterranean have shown that there was no significant or sealevel rise during the Messinian leaving a tectonic or climate control as the most likely cause for Messinian drying of the Mediterranean and that was followed in the early Pliocene by the re-flooding of Atlantic waters in the dessicated and evaporite-filled Mediterranean basin.

In this study, we integrate bathymetric, GPS data from the Tangier Peninsula and its offshore areas with paleostress measurements at 25 sites ranging in age from Jurassic to Miocene. Offshore data from the Strait of Gibraltar indicates that the main ENE-lineament on the seafloor is a major right-lateral strike-slip fault whose sense is consistent with: 1) WNW-trending GPS vectors; 2) the arrangement of positive restraining and negative releasing bends; 3) formation of a 15-20-km-wide syncline within the Strait that deepened with continued compression; and 5) the right-lateral offset of the Mesozoic Calcaire Dorsale Ridge by ~7 km. Paleostress sites onland in rocks of Oligocene to early Pliocene age indicate three events: 1) east-west compression of Miocene age inferred to record the formation and eastward motion of the Gibraltar arc; 2) NW-SE compression inferred to record the closure of Nubia and Iberia with compression of the Gibraltar arc; and 3) NE-SW compression inferred to represent continued compression of the Gibraltar arc that accompanied continued formation of the large syncline within the strait. We postulate that the offset of the highly resistant and 1-km-thick Calcaire Dorsale allowed the initial deep channels to open between the Atlantic and Mediterranean. We see no evidence for north-south-striking normal faults as postulated in strait-opening models based on rollback of the Gibraltar slab.

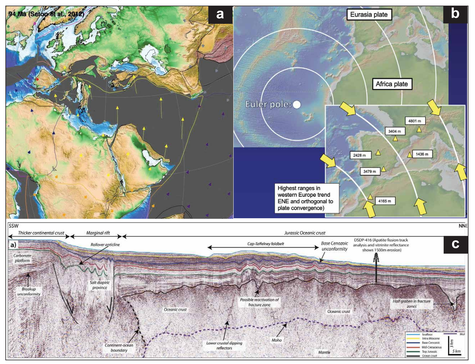
1. Along-strike structures of the Africa-Eurasia plate boundary





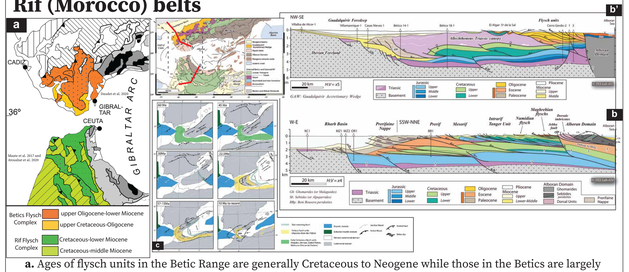
a. Simplified tectonic maps of Atlantic Ocean Azores-Gloria Fault Zone. **b.** north Africa and western mediterranean sea. Stars indicates main earthquakes, along with focal mechanisms and Seismicity distribution (M>4.5), black arrows indicates GPS vectors, red lines shows active faultsand black lines. Location of study area (white rectangle) **c.** Proposed plates boundaries in Gibraltar strait. Location of seismic lines.

2. Tectonic history of Africa-Eurasia convergence



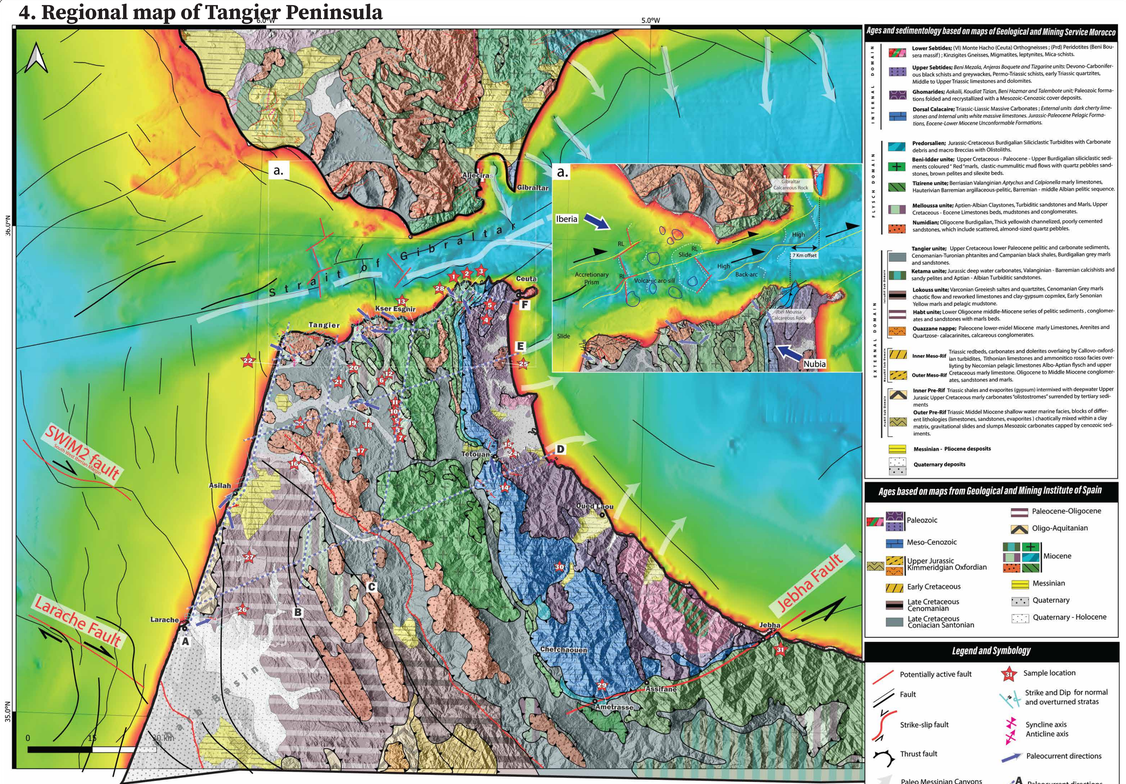
a. Plate kinematic reconstructions of Africa and Eurasia plates from Seton et al. (2012) with arrows showing the direction of plate convergence. **b.** Euler pole for Cenozoic Africa-Eurasia oblique convergence with small circles of rotation shown in white. Map shows the highest ranges in western Europe trending ENE and orthogonal to the oblique plate convergence direction. Highest elevations in the ranges are shown. **c.** North-south seismic reflection line from MCG-Geoex along the Atlantic margin of Morocco showing the large anticline formed in Jurassic-Cretaceous oceanic crust and inversion of the Jurassic rift in the coastal area.

3. Comparison of structure and age of the Betic (Spain) and Rif (Morocco) belts

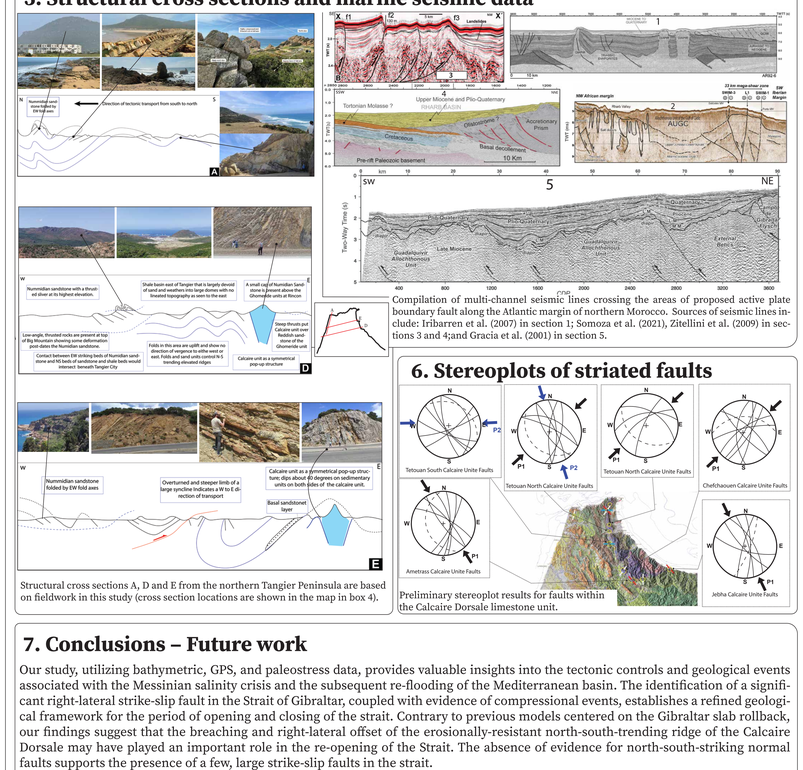


a. Ages of flysch units in the Betic Range are generally Cretaceous to Neogene while those in the Betics are largely Neogene. **b.** and **b'.** Geological cross sections for Rif and Betics belts are from Flinch and Soto (2017).

4. Regional map of Tangier Peninsula



5. Structural cross sections and marine seismic data



6. Stereoplots of striated faults

Preliminary stereoplot results for faults within the Calcaire Dorsale limestone unit.

7. Conclusions – Future work

Our study, utilizing bathymetric, GPS, and paleostress data, provides valuable insights into the tectonic controls and geological events associated with the Messinian salinity crisis and the subsequent re-flooding of the Mediterranean basin. The identification of a significant right-lateral strike-slip fault in the Strait of Gibraltar, coupled with evidence of compressional events, establishes a refined geological framework for the period of opening and closing of the strait. Contrary to previous models centered on the Gibraltar slab rollback, our findings suggest that the breaching and right-lateral offset of the erosionally-resistant north-south-trending ridge of the Calcaire Dorsale may have played an important role in the re-opening of the Strait. The absence of evidence for north-south-striking normal faults supports the presence of a few, large strike-slip faults in the strait.