PALEOCLIMATE

Lingering end to a salinity crisis

Modelling indicates that a return to fully normal marine conditions in the Mediterranean following the flooding that ended the Messinian Salinity Crisis was delayed by salt transfers and temporarily enhanced stratification.

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Starting around 6 million years ago, the Mediterranean was largely shut off from the Atlantic Ocean, with excess evaporation leading to the deposition of kilometre-thick sequences of salt throughout the basin[1]. Called the Messinian Salinity Crisis, reflecting its occurrence during the final stage of the Miocene epoch, drastic ecological shifts followed as geochemical conditions became increasingly harsh. Eventually, the basin became reconnected to the Atlantic some 5.3 million years ago, at the Miocene–Pliocene boundary, bringing about a return to marine conditions more similar to those of today. Writing in *Nature Geoscience*, Amarathunga and colleagues use numerical modelling and an analysis of proxy records to help resolve long-standing controversies regarding events that helped bring about the end of one of most prominent regional oceanographic perturbations in the geological record[2].

A restriction of the Gibraltar gateway (Fig. 1) between the Mediterranean and the Atlantic was the primary trigger of the Messinian Salinity Crisis, considering that no other gateways existed by which water could be exchanged between the Mediterranean Sea and the open ocean[3]. Substantial debate remains, however, regarding the extent of the base level oscillations that the basin experienced, with hypotheses ranging from almost complete desiccation to only a moderate lowering of sea level (on the scale of a few hundreds of metres)[4]. This sea level uncertainty also extends to the end of the Messinian Salinity Crisis. The classic explanation was that reconnection to the Atlantic led to rapid, catastrophic flooding into the partially desiccated basin by way of an enormous waterfall through the paleo Strait of Gibraltar. Due to the low sea level, this flood would have first filled the western Mediterranean before overtopping a sill near Sicily to finish flooding the eastern Mediterranean[5]. Alternatively, mainly based on the occurrence of low-salinity adapted ostracod fossils originating from the Paratethis megalake that existed at the time in the Black and Caspian seas and surrounding areas[6], others have suggested that the whole of the Mediterranean had already largely refilled before this reconnection[7]. This proposed high sea level interval, termed the 'Lago–Mare' or 'Lake–Sea' — during the late Messinian Salinity Crisis — is also thought to have had regular sea level oscillations on the order of 400 ± 100 m at Earth's axial precession frequency[8]. These oscillations may have also played a role in causing the final reconnection between the Mediterranean and Atlantic in either scenario.

Fig. 1 | A catastrophic flood through the Strait of Gibraltar, pictured here, into a partially dried out Mediterranean occurred 5.3 million years ago. Amarathunga et al. use fluid modelling to show that a transfer of brines from the west side of the Mediterranean basin led to a delay of tens of thousands of years in the reestablishment of normal marine conditions in the eastern Mediterranean.

Amarathunga and colleagues test how circulation and salinity levels in the Mediterranean likely changed at the end of the Messinian Salinity Crisis and soon after using a fluid physics model. They demonstrate that brines in the lower water column generated during the Messinian Salinity Crisis were transferred from the rapidly flooded western Mediterranean across the sill near Sicily to the eastern Mediterranean. This in turn led to the persistence of highly saline bottom waters tens of thousands of years beyond the end of the Messinian Salinity Crisis in the east relative to the west sides of the basin before complete dilution by Atlantic seawater. An organic matter-rich sapropel layer in the eastern Mediterranean throughout this interval — which the authors call 'Mystery Sapropel' — following the terminology introduced during Deep Sea Drilling Project (DSDP) and which they analyse geochemically — is found to have been the result of salinity-induced water column stratification. Notably, they suggest that this stratification-induced delay was about one precessional cycle in length or about 26,000 years. The modelling results were validated using proxy records that traced how salinity and the geochemical indications of ocean stratification changed during and immediately after the latest Messinian Salinity Crisis, records which had previously been difficult to reconcile. These results reshape our understanding of the hotly debated termination of the Messinian Salinity Crisis.

Critically, the authors conclusively show that, by running their model with various boundary conditions, only the catastrophic flooding scenario is plausible. If the Mediterranean had already largely been refilled before reconnection with the Atlantic, the salinity stratification would have occurred in both the eastern and western basins, which is inconsistent with geochemical data constraints. On the other hand, their findings regarding the transport and concentration of residual brines from the western Mediterranean into eastern Mediterranean bottom waters by a flood also rule out the hypothesis that the Mediterranean became fully desiccated, at least towards the end of the Messinian Salinity Crisis. The model results require that the western and eastern Mediterranean Sea levels were ~1,450–1,700 metres and ~1,750–2,000 metres below the Atlantic level, respectively, at the onset of the terminal flood. Reconstructions of the paleo-water depth of the Mediterranean, accounting for lithospheric rebound and sea level changes[9], suggest that the seabed was considerably deeper than these reconstructed levels, allowing of a residual brine layer well in excess of 1 km in the Western Mediterranean and probably in excess of 2 km in the Eastern Mediterranean before the flood. A completely or largely desiccated Mediterranean would have left no residual brine reservoir. The model results further provide a solid constraint to the depth of the Sicily sill, which is found to have been ~500 m below the Atlantic sea level, a finding that will help refine hydrological models of the evolution of the Mediterranean throughout the Messinian Salinity Crisis.

The Messinian Salinity Crisis is typically characterized by the widespread development of hyper- and hyposaline environments during the latest part of the Miocene, making it surprising that the salinity crisis actually persisted, at least in the Eastern Mediterranean, into the early Pliocene. Furthermore, these results show that the Mystery Sapropel was a sedimentary expression of water column conditions at the end of the Messinian Salinity Crisis. It's shown that this relatively long-lived sapropel uniquely spans a solar insolation precessional cycle, which distinguishes it from all other shorter-duration Mediterranean sapropels from the Miocene or in the Pleistocene[10]. The Mystery Sapropel is a clear demonstration of the resilient recovery of marine ecosystems despite ongoing salinity-induced stress.

Overall, this study demonstrates once again the extraordinary value of the scientific ocean drilling legacy data as a long-lasting source of primary information for application of the evolving analytical and numerical modelling techniques. Continuing scientific ocean drilling efforts in deep Mediterranean basins is the only way to improve understanding of both the Messinian Salinity Crisis and many older phases of salt deposition throughout Earth history. ❒

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Competing interests

The author declares no competing interests.