The Messinian evaporites in the Mediterranean: a box model study

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1. Introduction

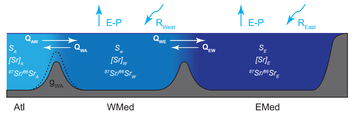
Many aspects of the Mediterranean massive evaporite layers, deposited during the Messinian Salinity Crisis (MSC), remain controversial and unexplored.

Combining strontium isotope and salinity data with results from a box model, we investigate if and how the fresh water budget and the size of the Atlantic-Mediterranean gateway varied during the Late Miocene.

Dating of the onset of marginal gypsum formation shows it is synchronous throughout the Mediterranean. The deep water halite deposits, on the other hand, are hard to date and are substantially thicker in the EMed than in the WMed. We examine, with another box model, the spatial and temporal evolution of salinity in the Mediterranean with different fresh water budgets and gateway sizes in order to explain the observed synchroneity and different halite thicknesses.

2. Models

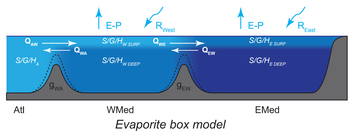
Sr concentration, Sr-isotope ratio and a Late Miocene water budget are incorporated in a 2-box model. Outflow (Q) from each basin is linearly dependent on the salinity contrast between the basins; $Q=g_{XY}(S_X-S_Y)$, where g_{XY} is the linear exchange coefficient. g_{XY} can be varied between 10^6 and 10^1, corresponding to an open and very restricted gateway, respectively.



Sr box model

This *Sr box model* allows for examination of the temporal evolution of salt and Sr-isotope ratio as a function of the individual hydrologic fluxes (Atlantic in and outflow, river input and evaporation).

After adding a parametrisation of watercolumn stratification and evaporite formation, the *evaporite box model* can be used to examine timing and thickness of gypsum and halite.

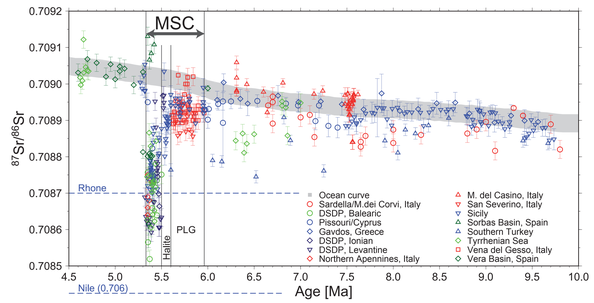


Evaporite box model

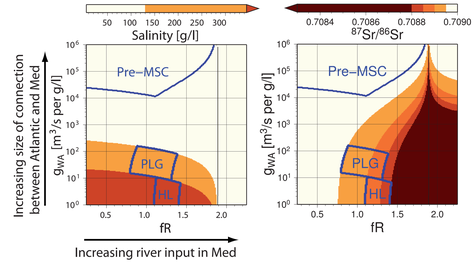
Gypsum deposition commences in a basin once the salinity in one of the layers exceeds 145 g/l, halite deposition starts above 350 g/l.

3. Strontium isotopes

The Late Miocene Sr-curve
Pre-MSC $^{87}Sr/^{86}Sr$ values only deviate from coeval oceanic values (shaded area) in marginal basins and the Tyrrhenian Sea. During the MSC $^{87}Sr/^{86}Sr$ values drop significantly from ocean values to 0.7085 in the last stage of the MSC. After the Pliocene reflooding $^{87}Sr/^{86}Sr$ values shift back to oceanic values.



Model results
Salinity and $^{87}Sr/^{86}Sr$ values are known for three Late Miocene time intervals; pre-MSC,Primary Lower Gypsum (PLG) and halite (HL). Locating the corresponding range in our model results we obtain an estimate of fresh water budget and gateway restriction in these intervals.



Salinity and $^{87}Sr/^{86}Sr$ results with interpretation from a model with a late Miocene geometry and water budget as a function of gateway size (g_{WA}) and river input (x R)

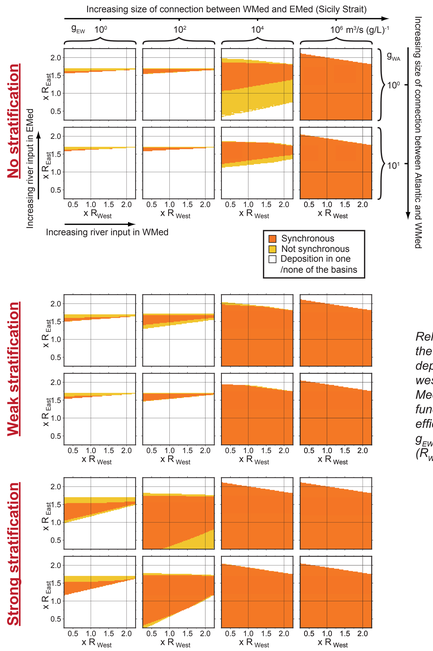
Pre-MSC: open marine salinities and $^{87}Sr/^{86}Sr$ values correspond to a model with non-restricted gateway exchange with the Atlantic.
MSC (PLG): gypsum saturation and $^{87}Sr/^{86}Sr$ values below the oceanic range correspond to a model with restricted gateways and an average river input and evaporation
MSC (HL): halite saturation and low $^{87}Sr/^{86}Sr$ values correspond to a model with almost closed gateways and a slightly wetter climate.

The pathway between these stages delineates simple gateway restriction with a slightly wetter climate during the HL stage.

4. Primary Lower Gypsum

Taking into account the uncertainties associated with the dating, gypsum formation at the onset of the MSC should commence with a maximum difference of ~20 kyr between the basins to be considered synchronous.

The largest range of parameters with synchronous onset of gypsum formation is found in settings with a large Strait of Sicily. This range increases by introducing stratification.



Relative timing of the onset of gypsum deposition in the western and eastern Mediterranean as a function of gateway efficiencies (g_{WA} and g_{EW}) and river inputs (R_{West} and R_{East}).

5. Halite

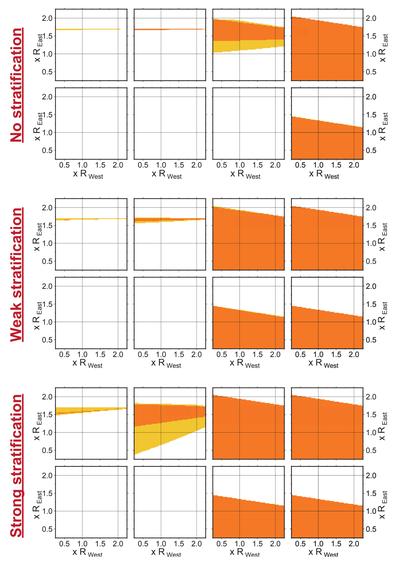
Because the Messinian halites are mainly found in the deep basins, their origin and timing of onset are not well known. As for the PLG, for those model results that show halite formation in both the WMed and EMed, we can determine whether the onset of halite formation is synchronous.

In the parameter range where halite is formed in both basins, halite formation is generally synchronous. Only when the Strait of Sicily is sufficiently restricted, is asynchronous formation possible.

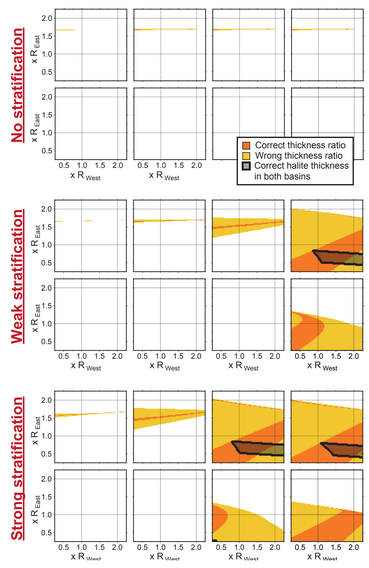
While the observed thickness of gypsum in the WMed and EMed is similar, the halite thickness in the EMed (2 km) is more than twice that of the WMed (< 1 km). These differences are as yet unexplained. The duration of deep basinal halite formation is largely unconstrained, but extrapolating from the few marginal basin outcrops, it is placed in the 60 kyr interval between 5.61 and 5.55 Ma.

Halite thicknesses formed in the model in 60 kyr should approximate the observed thicknesses and have a ratio between EMed and WMed thickness of ~2. Both requirements are only met in a small parameter range (in the orange area within the black outline) in settings with stratification, a large Strait of Sicily and a highly restricted Atlantic-Mediterranean gateway.

The different thicknesses can be explained by a different ratio of E-P-R over basin volume, the main control on the net salt gain per unit volume for each basin.

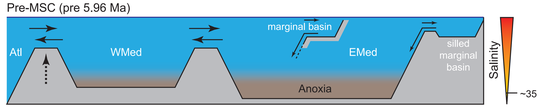


Similar to the figure on the left. Relative timing of the onset of halite deposition in the western and eastern Mediterranean as a function of gateway efficiencies and river inputs.

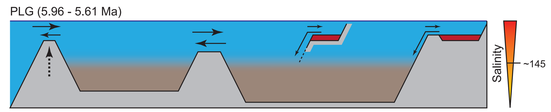


Colours indicate whether the ratio between EMed and WMed halite thicknesses is correct. The outlined areas indicate where modelled halite thicknesses fit with observations in both basins.

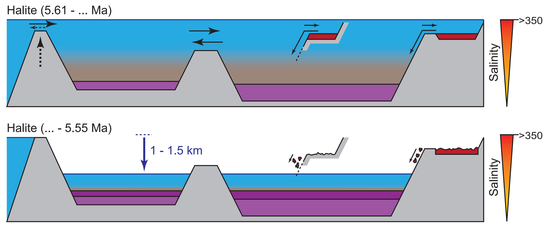
6. MSC scenario



Before the MSC, oxygen and carbon isotopes, and the occurrence of sapropels indicate some restriction of the Atlantic-Mediterranean gateway and anoxia in the deep basins.



A restriction of the Atlantic-Mediterranean gateway causes the Mediterranean salinity to rise. Neither the fresh water budget or the size of the Strait of Sicily changes. Gypsum starts to form in the marginal basins, while it is inhibited by anoxia in the deep basins.



A further restriction of the Atlantic-Mediterranean gateway forces the Mediterranean to halite saturation. Halite is precipitated in the deep basins from the denser deep water layer. Sometime during halite deposition the Atlantic-Mediterranean gateway closes completely, leading to a large sea level drop and erosion along the margins. During the sea level fall, at most 33% of the observed halite deposits can be formed. A connection with the Atlantic is necessary during part of this phase to explain the whole halite volume.

References

R.P.M. Topper, R. Flecker, P.Th. Meijer and M.J.R. Wortel, 2011. A box model of the Late Miocene Mediterranean Sea: Implications from combined $^{87}Sr/^{86}Sr$ and salinity data. Paleoceanography 26, PA3223.
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