A box model study of the Late Miocene Mediterranean
Strontium isotopes and evaporites

ISES

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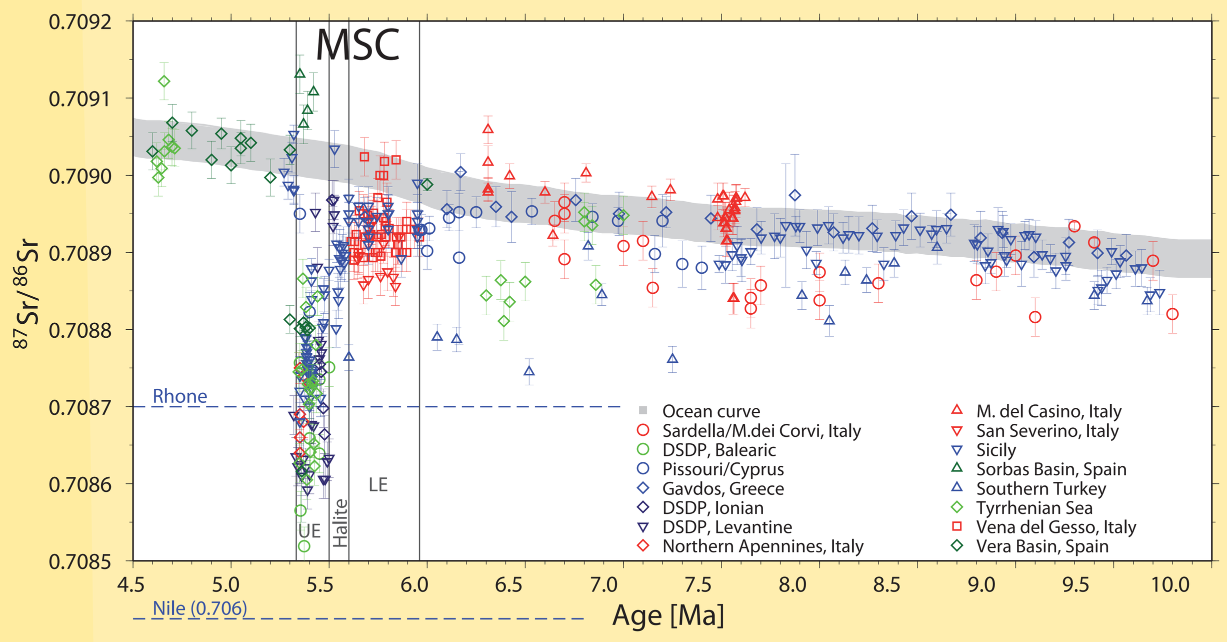
1. Introduction

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

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

Secondly, we examine the spatial and temporal evolution of salinity in the Mediterranean. We focus on the possibility of reaching gypsum saturation with different fresh water budgets and strait sizes, the difference in timing of onset of gypsum deposition between the WMed and EMed, and the thickness of halite deposits during the MSC.



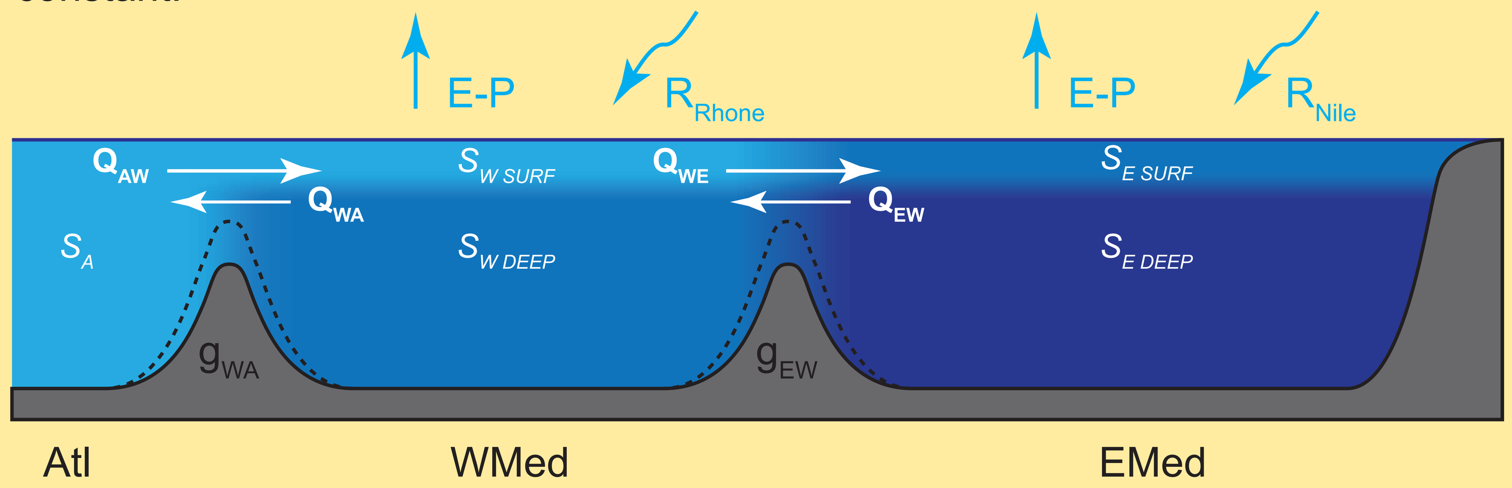
3. Strontium isotopes

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 upper evaporites. After the Zanclean reflooding $^{87}Sr/^{86}Sr$ values shift back to oceanic values.

2. Model

Sr concentration, Sr-isotope ratio and a Late Miocene water budget are incorporated in a 2-box model which quantifies the water and salt budget of the Mediterranean basins under specified conditions of connectivity between the basins, with the Atlantic ocean and atmospheric fluxes. Outflow from each basin is linearly dependent on the salinity contrast between the basins; $Q = g\,(S_2 - S_1)$, where g is the linear exchange coefficient. g can be varied between 10^6 and 10^1, corresponding to an open and very restricted gateway, respectively. Inflow compensates for outflow and fresh water deficit in order to keep the sea level constant.



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

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.

Model results

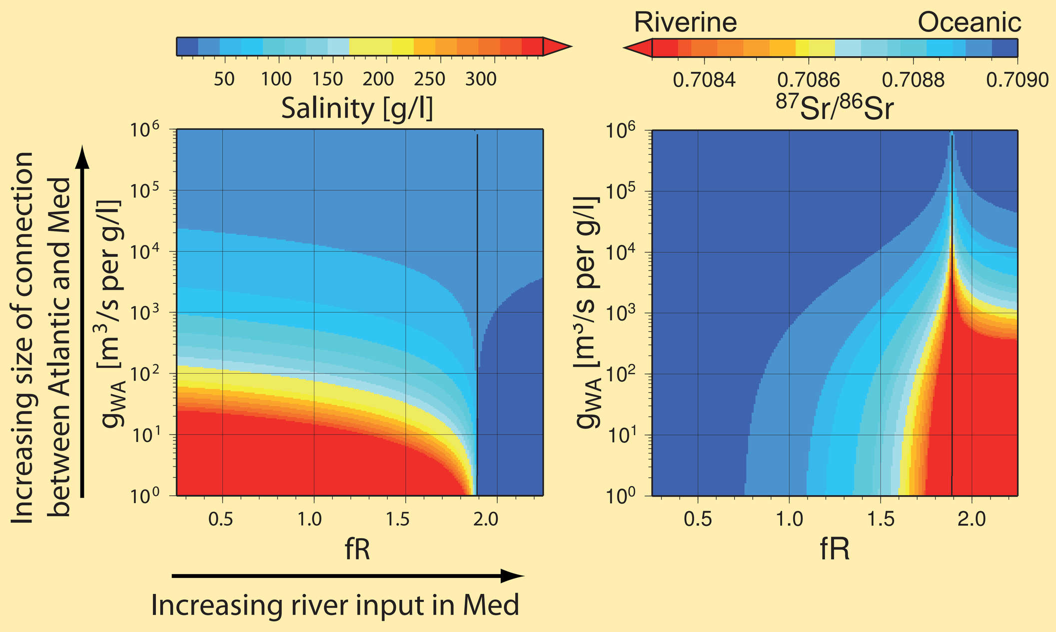
Salinity and $^{87}Sr/^{86}Sr$ values are known for three Late Miocene time intervals; pre-MSC, Lower Evaporites (LE) and halite (HL). Locating the corresponding range in our model results we obtain an estimate of fresh water budget and gateway restriction in these intervals.

Pre-MSC: open marine salinities and $^{87}Sr/^{86}Sr$ values correspond to a model with non-restricted gateway exchange with the Atlantic.

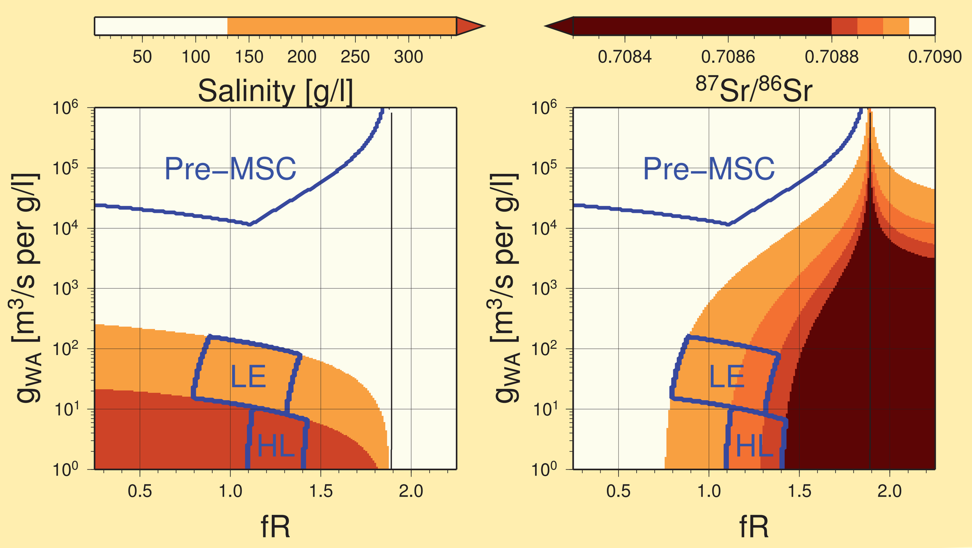
MSC (LE): gypsum saturation and $^{87}Sr/^{86}Sr$ values below the oceanic range correspond to a model with restricted gateways and an average river input and evaporation

MSC (HL): halite saturation and low $^{87}Sr/^{86}Sr$ values correspond to a model with almost closed gateways and a slightly wetter climate.

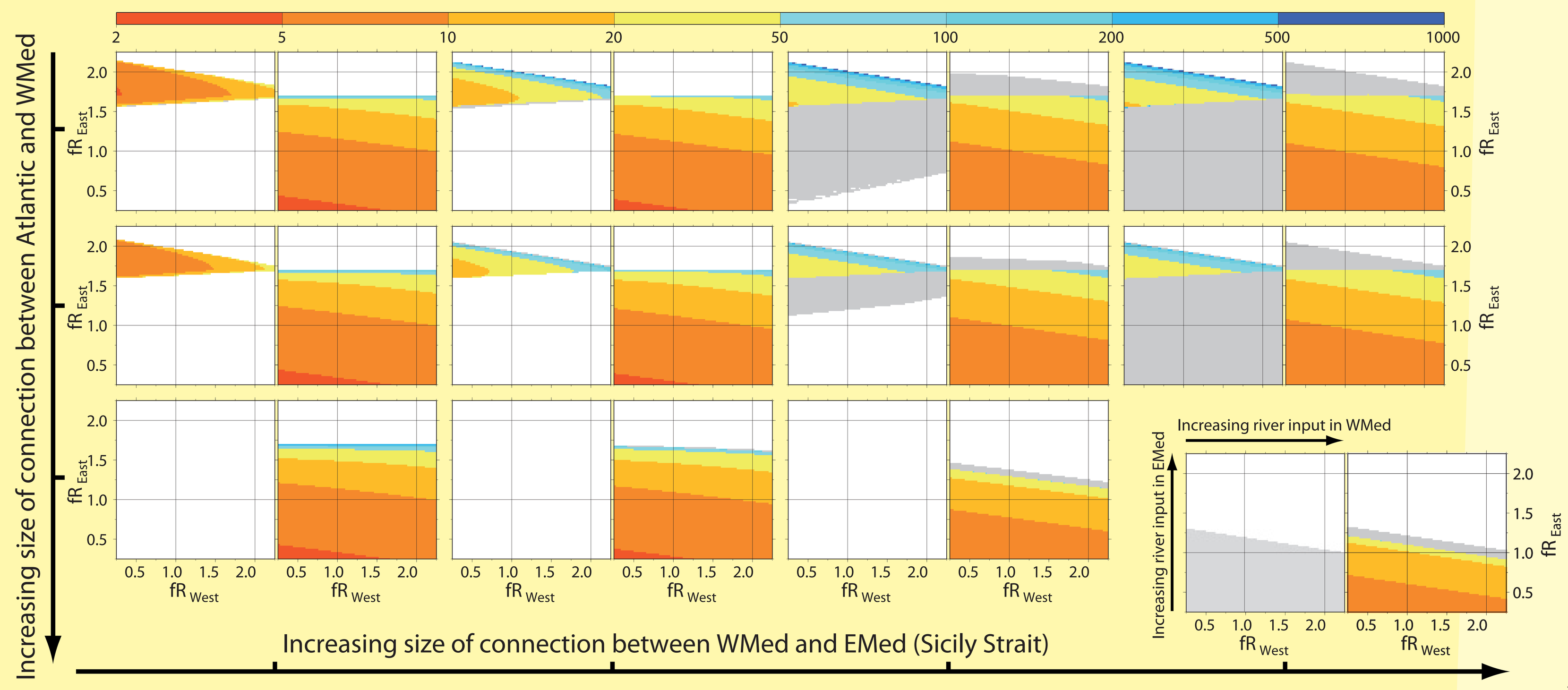
The pathway between these stages delineates simple gateway restriction with a slightly wetter climate during the HL stage.



Salinity and $^{87}Sr/^{86}Sr$ results without (above) and with (below) interpretation from a model with a late Miocene geometry and water budget as a function of gateway size (g_{WA}) and river input (fR)



4. Evaporites: differences in the Mediterranean

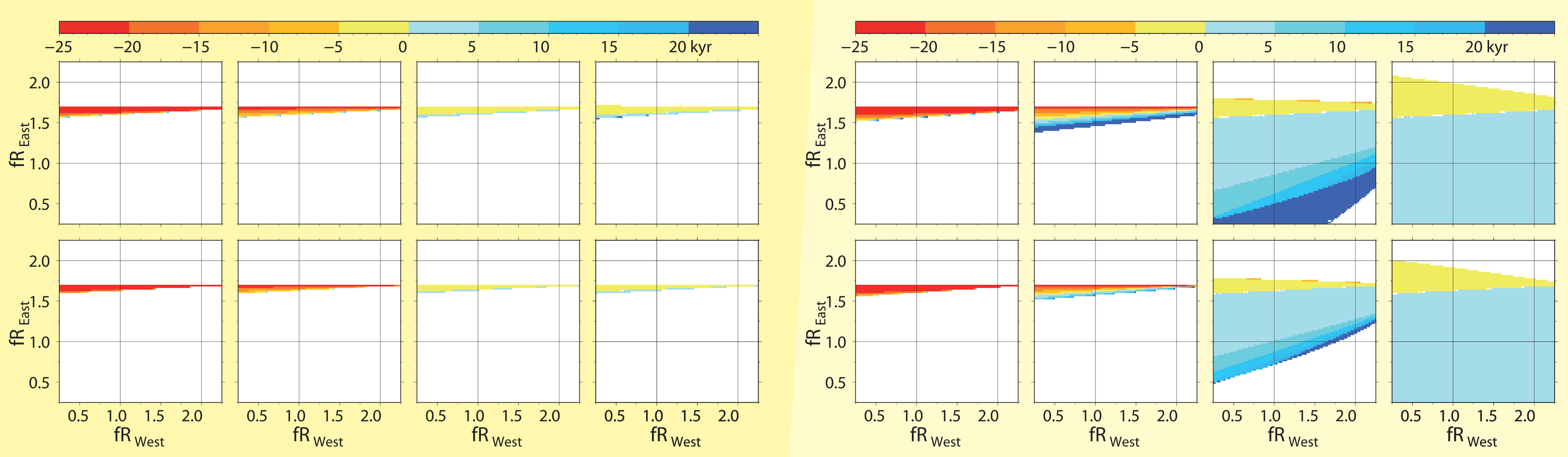


Time to gypsum saturation.
Shaded areas reach a gypsum concentration > 95% of the gypsum saturation value.
(left) no stratification
(right) with stratification

While the observed thickness of gypsum in the WMed and EMed is similar, the halite thickness in the EMed is more than twice that of the WMed. These differences are as yet unexplained.

The time to reach saturation in each of the Mediterranean basins depends on the fresh water budget and the size of the gateways (Gibraltar arc and Sicily).

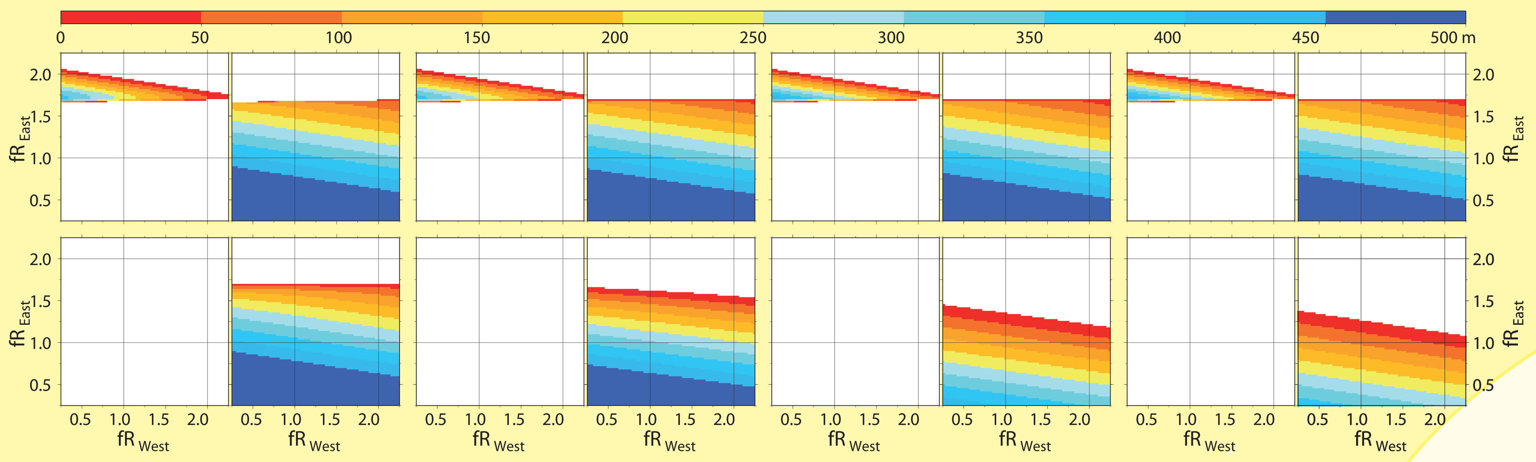
In general, a smaller connection with the Atlantic and less river input lead to faster increasing salinity in the Mediterranean basins. The size of the Strait of Sicily determines the distribution of salt between WMed and EMed, a large connection leads to a more even distribution and slower salinity increase in the EMed.



Difference in time to saturation between the WMed and EMed
$t_{SAT\,WMed} - t_{SAT\,EMed}$
(left) no stratification
(right) with stratification

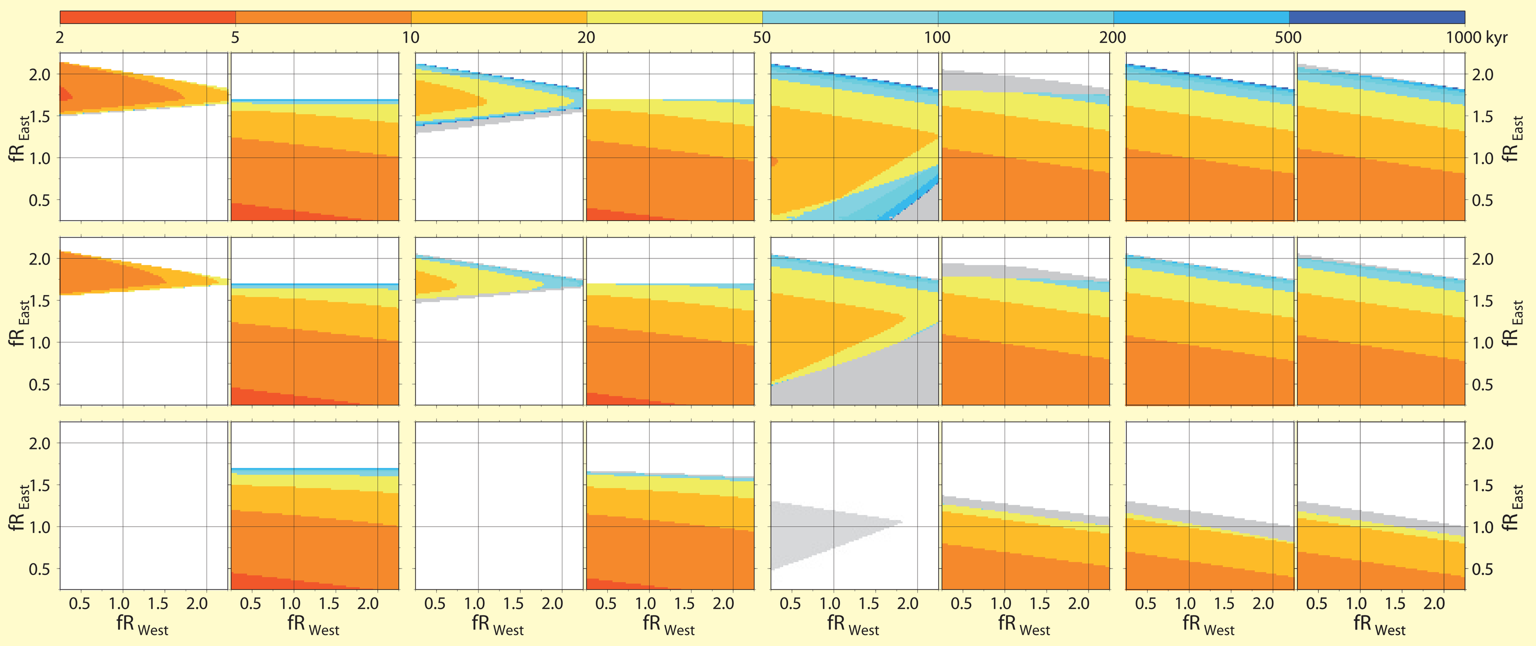
Synchronous onset of the MSC is evidenced by a similar age of the first LE gypsum bed in both WMed and EMed marginal sequences. Taking into account the uncertainties associated with the dating, gypsum saturation should be reached with a maximum difference of ~20 kyr between the basins. The parameter range in which gypsum saturation is reached in both basins and within 20 kyr of each other is very limited, and restricted to scenarios with a large Sicily strait.

Once halite saturation is reached in one of the Mediterranean basins, we can calculate the amount of halite deposition in the next 50 kyr to get an estimate of possible halite accumulation during the second MSC stage. Only within a very limited parameter range is halite deposition in both basins possible.



Modelled halite thickness *as a layer with constant thickness spread over the whole water covered area of the Mediterranean.*
(left) no stratification
(right) with stratification

5. Evaporites: the role of stratification

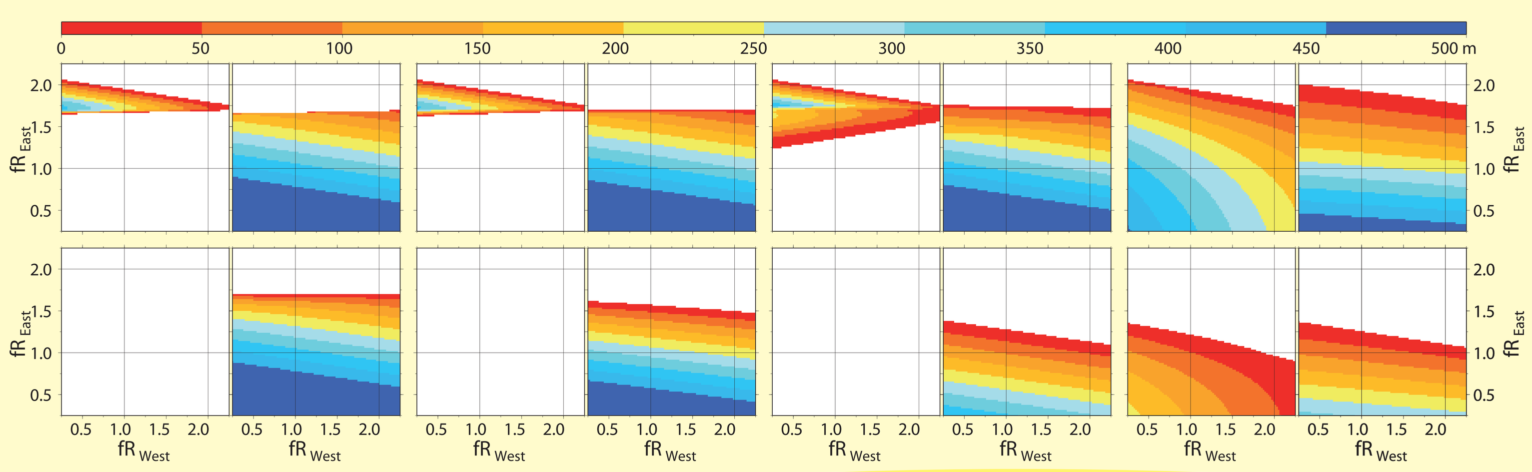


Stratification of the water column changes the vertical distribution of salt; the surface layer becomes fresher, the deep layer saltier.

With increasing stratification, surficial salt transport between the basins becomes less, due to lower surface layer salinities, while deep layer transport increases. This results in slower salinity increase in the EMed and a higher steady state salinity in the WMed. With increasing stratification and a larger Sicily strait, the possibility of gypsum deposition in the WMed increases.

Where the parameter range with gypsum saturation in both basins within 20 kyr of each other was very limited without stratification, it has significantly increased with stratification, especially when the Sicily strait is large.

Compared to the no stratification results the EMed halite thickness generally decreases whereas it increases in the WMed with stratification. When comparing model results with field observations, one must keep in mind that modelled thicknesses are minimum estimates because deposition did not take place in the whole Mediterranean. In a smaller depositional area evaporite thicknesses would be larger.



6. Conclusions

- Simple gateway restriction can cause the onset of the MSC.
- The range of water budgets with which gypsum formation in both Mediterranean basins is possible, is small. It is largest with significant water column stratification and a large connection between WMed and EMed.
- The range of possible evaporite thicknesses, as modelled for the HL phase of the MSC, is large. There are many possible combinations of fresh water budget, gateway sizes and stratification with which observed thicknesses can be reproduced.