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Primary Evaporites for the Messinian Salinity Crisis: the shallow gypsum vs. deep dolomite formation paradox solved

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The Messinian Salinity Crisis (MSC) is a dramatic event that took place ∼ 5.9 Ma ago, and resulted in the deposition of 0.3-3 km thick evaporites at the Mediterranean seafloor. A considerable and long-lasting controversy existed on the modes of their formation. During the CIESM Almeria Workshop a consensus was reached on several aspects. In addition, remaining issues to be solved were identified, such as for the observed shallow gypsum versus deep dolostone deposits for the early phase of MSC.

The onset of MSC is marked by deposition of gypsum/sapropel-like alternations, thought to relate to arid/humid climate conditions. Gypsum precipitation only occurred at marginal settings, while dolomite containing rocks have been reported from deeper settings. A range of potential explanations have been reported, most of which cannot satisfactorily explain all observations. Biogeochemical processes during MSC are poorly understood and commonly neglected. These may, however, explain that different deposits formed in shallow versus deep environments without needing exceptional physical boundary conditions for each.

We present here a unifying mechanism in which gypsum formation occurs at all shallow water depths but its preservation is mostly limited to shallow sedimentary settings. In contrast, ongoing anoxic organic matter (OM) degradation processes in the deep basin result in the formation of dolomite. Gypsum precipitation in evaporating seawater takes place at 3-7 times concentrated seawater; seawater is always largely oversaturated relative to dolomite but its formation is thought to be inhibited by the presence of dissolved sulphate. Thus the conditions for formation of gypsum exclude those for the formation of dolomite and vice versa. Another process that links the saturation states of gypsum and dolomite is that of OM degradation by sulphate reduction. In stagnant deep water, oxygen is rapidly depleted through OM degradation, then sulphate becomes the main oxidant for OM mineralization, thus reducing the deep-water sulphate content. In addition, considerable amounts of dissolved carbonate are formed. This means that low-sulphate conditions as for MSC deepwater, i.e. unfavorable conditions for gypsum formation, always coincide with anoxic, i.e. oxygen-free conditions. Thus one would expect a bath-tub rim of gypsum at all shallow depths, but gypsum appears mainly at silled marginal basins. However, a thick package of heavy gypsum on top of more liquid mud in a marginal/slope setting is highly unstable, thus any physical disturbance such as tectonic activity or sea-level change, would easily lead to downslope transport of such marginal gypsum deposits. The absence of gypsum and the presence of erosional unconformities at the sill-less Mediterranean passive margins concord to such removal mechanism. In addition, large-scale re-sedimentation of gypsum has also been found for deep Messinian settings in the Northern Apennines and Sicily. Only at those marginal settings that were silled, the marginal gypsum deposits have been preserved. Including the dynamic biogeochemical processes in the thusfar static interpretations of evaporite formation mechanisms can thus account for the paradoxal, isochronous formation of shallow gypsum and deep-dolomite during the early MSC (1).

(1) De Lange G.J. and Krijgsman W. (2010) Mar. Geol. 275, 273-277.