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The deep record of the Messinian salinity crisis: Evidence of a non-desiccated Mediterranean Sea

Stefano Lugli [a,*], Vinicio Manzi [b], Marco Roveri [b], B. Charlotte Schreiber [c]

[a] Dipartimento di Scienze Chimiche e Geologiche, Università degli Studi di Modena e Reggio Emilia, Modena, Italy
[b] Dipartimento di Fisica e Scienze della Terra, Università degli Studi di Parma, Parma, Italy
[c] Department of Earth and Space Sciences, University of WA, Seattle, USA

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ABSTRACT

This research is focused on a complete reexamination of the evaporite facies present in all the cores that cut through the topmost deposits of the Messinian salinity crisis lying below the floor of the Mediterranean Sea (DSDP Legs 13 and 42A, ODP Legs 107 and 161). This review suggests that the uppermost evaporite units in both western and eastern deep Mediterranean basins consist mainly of clastic (gypsrudite, gypsarenite and gypsiltite) and fully subaqueous deposits (laminar gypsum, selenite and cumulate halite) that are partially affected by burial anhydritization and tectonic-induced recrystallization. No unequivocal evidence of shallow water or even supratidal (sabkha) deposition is in evidence, suggesting that at the very last phase of the salinity crisis the Mediterranean Sea did not experience desiccation, but that deposition took place under permanent subaqueous conditions.

1. Introduction

More than 40 years have passed since the discovery of the evaporite giants buried below the Mediterranean floor and the enunciation of the Messinian paradigm claiming for the deep desiccation of the Mediterranean (Hsü et al., 1973a,b). The formulation of the “deep basin shallow water basin” was based on three main points: i) the recognition of very deep water deposits before and after the evaporites suggesting the presence of a deep basin well before the onset of the salinity crisis; ii) the widespread erosional features along the margin of the Mediterranean that were supposed to be subaerially exposed during the deep desiccation iii) the recovery of evaporitic facies in the uppermost portion of the thick Messinian evaporite unit that have been interpreted as supratidal deposits accumulated in a sabkha environment.

The study of the Messinian salinity crisis in the Mediterranean has moved a considerable step forward in the last decade. The debate on the origin and evolution of the crisis is still an hot topic (see Rouchy and Caruso, 2006 and Roveri et al., 2014a, for a summary of the controversy), but a reliable stratigraphic framework largely shared by the scientific community is now available as a basis for discussion (CIESM, 2008; Roveri et al., 2014a) and the onshore relationships between shallow and relatively deep evaporite facies have been largely clarified (Manzi et al., 2007, Roveri et al., 2008).

The most important problem in understanding the salinity crisis is that the largest volume of the giant evaporite deposit lies unexamined beneath the floor of the Mediterranean. This large portion of the sedimentary products of the salinity crisis was sampled only for several meters by a few cores drilled in the 70s and 90s. The decision to limit drilling and not to penetrate the evaporites more than a few meters was taken to avoid a possible hydrocarbon blowout in the Mediterranean, an event that would have possibly been even more catastrophic than that observed in 2010 in the Gulf of Mexico.

Until a new drilling campaign will be launched to sample those deposits, utilizing new technologies, that were not available in the past, the result is that any discussion about depositional environments (shallow vs. deep evaporite facies) is still open to considerable speculation.

Although there is only sparse sampling of the very thick successions that lay below the floor of the Mediterranean, these short cores are pivotal for the understanding of the crisis evolution. On the other hand, no modern evaporite facies analysis have been performed on most of the few meters of evaporites recovered from ODP-DSDP wells, the only descriptions being those compiled during the recovery or shortly thereafter. Important exception is the work of Hardie and Lowenstein (2004), who questioned the original facies interpretation given by the scholars of the original deep desiccation model (Hsü et al., 1973a,b), suggesting that most interpreted shallow-water facies features described beneath the floor of the Mediterranean may be the result of deep-water deposition. Unfortunately this process of re-examination was restricted only to the DSDP drillcores of Legs 13

* Corresponding author at: Dipartimento di Scienze Chimiche e Geologiche Università degli Studi di Modena e Reggio Emilia Via Campi 103, 41125 Modena, Italy.
E-mail address: stefano.lugli@unimore.it (S. Lugli).

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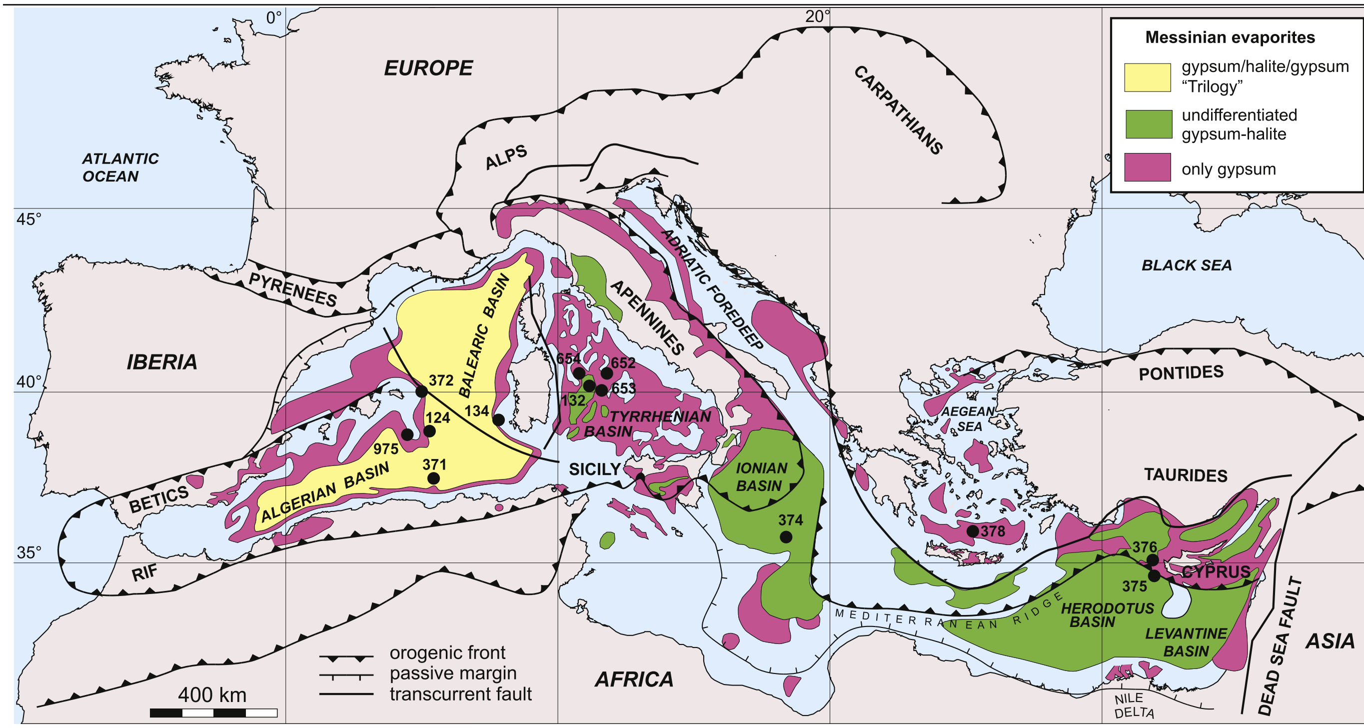

Fig. 1. Messinian evaporite lithological associations in the Mediterranean. ODP and DSDP drilling sites are also shown (black dots).

(1970) and 42A (1975). The same hypothesis was put forward by Roveri et al. (2001), Manzi et al. (2005) and Roveri and Manzi (2006), based on the facies analysis carried out on the resedimented evaporites of the Northern Apennines foredeep, and by Lofi et al. (2005), based on the new seismic data of deep Mediterranean settings.

With the aim of providing a new data set for this discussion, we performed a complete re-examination of the petrography and sedimentology of the evaporite facies of all the cores that are available to the scientific community (Fig. 1): not only from DSDP Legs 13 and 42A, but also from ODP Legs 107 (1990), 161 (1999). These are the very same set of cores that were considered to provide the evidence of the desiccation of the Mediterranean Sea during the Messinian.

2. The Messinian salinity crisis: a facies problem

The Messinian salinity crisis is one of the most complex geological events that happened on our planet. The degree of complexity of this event that turned the Mediterranean into a giant salina producing a biological-catastrophy for most marine species is well represented by the many different alternative hypotheses that have been proposed to unravel its origin and evolution. The consequence has been a scientific controversy that lasted since the discovery of the evaporite sequences buried below the Mediterranean floor (see Rouchy and Caruso, 2006).

One potentially comprehensive approach for the understanding this crisis is to unravel the intricate evaporite facies array that was deposited in the different Mediterranean areas (Fig. 1).

Although we are aware that no modern analogs are available to compare all the Messinian facies architecture, at a first glance the evaporite products are surprisingly similar to what one would expect just by simple evaporation of seawater. Evaporite deposits range from carbonate (the first to precipitate from seawater) to gypsum ($CaSO_4 \cdot 2H_2O$), halite (NaCl), kainite ($MgSO_4 \cdot KCl \cdot 3H_2O$) and finally bishofite ($MgCl_2 \cdot 6H_2O$; the last to precipitate), a rather rare very soluble salt that has an extremely low potential of preservation in the rock record and yet is present in the Messinian succession in Sicily.

Yet a simple facies comparison with modern evaporites forming in the Mediterranean, both natural (sabkhas and associated salinas in North Africa) and artificial (commercial solar works), reveals many profound differences, suggesting that still other mechanisms may have influenced precipitation and sediment preservation, to some degree, in the past. One of these processes is probably the vast input of freshwater into the basin during gypsum deposition, as revealed by the Sr isotope geochemistry (Flecker and Ellam 2006; Lugli et al., 2010; Roveri et al., 2014b) and fluid inclusion data (Natalicchio et al., 2014). Another important factor may be the organic matter associated with the sediments, as accumulations of cyanobacteria and archea are included in most of the evaporite products, especially gypsum (Panieri et al., 2010) and argillaceous sediments (Dela Pierre et al., 2014). These important aspects still need to be fully explored.

Even more different and unexpected is the facies association and architecture of these deposits that are arranged in a fashion that exclude the reasonable, but in a way simplistic, view that different evaporite

Fig. 2. A) Core slab of halite rock from Site 134 showing sandy silt (light gray at the top) and fine-grained halite cube cumulate (light gray at the bottom). The clastic layer is composed of corroded cubic halite, planktonic forams, quartz, feldspar and glauconite grains. The white nodules consist of felted displacive anhydrite. This sample is 10 cm below the core section cut by a crack originally interpreted as a desiccation feature by Hsü et al. (1973a and b) and displays the same facies association (see also Fig. 4). A thin section of the core is shown in Figs. 3A and 4G and F. B) Core slab of halite rock made up of clear blocky and elongated crystals. This rock appears to have recrystallized during tectonic flow (see Fig. 3B for a thin section of a similar rock). Relict of the original layering is the dark banding appearing on the top of the sample and consisting of scattered argillaceous material. Site 376. C) Core slab of a laminar rock consisting of fine-grained graded granular gypsum with a clastic gypsum intercalation (at center of picture). A thin section of a similar cumulite rock is shown in Fig. 3C. Site 654. D) Core slab of a undulate coarse gypsum laminite consisting of mm-size granular crystals (light gray beds) draped by fine-grained gypsum cumulate (dark laminae). A thin section of a similar cumulite rock is shown in Fig. 3E. Site 975. E) Core slab of a deformed undulate coarse gypsum laminite consisting of mm-size granular crystals (light gray beds) draped by fine-grained gypsum cumulate (dark laminae). Site 653. F) Core slab of an anhydrite rock consisting of large elongated nodules possibly partially modified by pressure solution, but showing some pseudomorphs after swallow tail selenite crystals. Arrow is pointing to the re-entrant angle of a swallow tail crystal. Site 124. G) Core slab of graded gypsarenite–gypsrudite rock consisting of corroded selenite fragments. A thin section of this rock is shown in Fig. 3I. Site 654. H) Core slab of a cross bedded clastic gypsum rock consisting of reworked granular cumulate gypsum. A thin section of this rock is shown in Fig. 3L. Site 654.