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Research paper

Messinian evaporite deposition during sea level rise in the Gulf of Lions (Western Mediterranean)

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ABSTRACT

The Messinian Salinity Crisis resulted from desiccation of the Mediterranean Sea after its isolation from the Atlantic Ocean at the end of the Miocene. Stratal geometry tied to borehole data in the Gulf of Lions show that the pre-crisis continental shelf has been eroded during a major sea-level fall and that sediments from this erosion have been deposited in the basin. This detrital package is onlapped by high amplitude seismic reflectors overlain by the “Messinian Salt” and the “Upper Evaporites”. Towards the shelf, the transition between regressive deposits and overlying onlapping sediments is characterised by a wave-ravinement surface, suggesting that a significant part of the onlapping reflectors and overlying Messinian Evaporites were deposited during a relatively slow landward migration of the shoreline. The clear boundary between the smooth wave-ravinement surface and the subaerial Messinian Erosional Surface observed on the Gulf of Lions shelf and onshore in the Rhône valley is interpreted to have resulted from a rapid acceleration of the Mediterranean sea level rise at the end of the Messinian Salinity Crisis. Numerical simulation of this cycle of sea level change during the Messinian Salinity Crisis and of precipitation of thick evaporites during the slow sea level rise shows that this scenario can be modelled assuming a value of evaporation minus precipitation of 1.75 $m^3/m^2/yr$ in the deep Mediterranean basins.

1. Introduction

The largest known sea level fall on the Earth resulted from the isolation of the Mediterranean Sea from the Atlantic Ocean at the end of the Miocene. This isolation, associated with a significant evaporation rate, led to the deposition of a series of thick evaporites in the Mediterranean basins (Hsü et al., 1973a) and intense subaerial erosion at its periphery (Barber, 1981; Barr and Walker, 1973; Chumakov, 1973; Clauzon, 1973, 1978, 1982; Ryan and Cita, 1978; Savoye and Piper, 1991). The “desiccated, deep basin” model (Hsü, 1972b; Cita, 1973; Hsü et al., 1973a; Ryan, 1973) explains this depositional event, known as the Messinian Salinity Crisis (MSC), by a high evaporation rate and sea-level drop of around 1500 m in a

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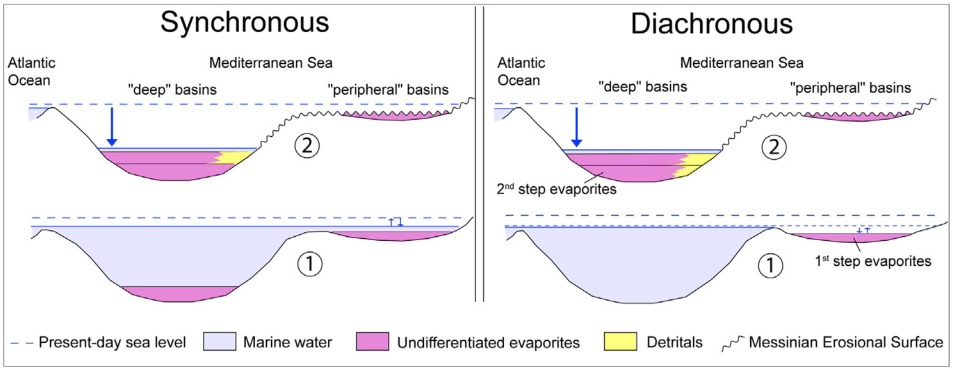

Figure 1. The synchronous and diachronous scenarios for the deposition of the Messinian evaporites in the Mediterranean Sea. In the synchronous scenario phase 1 corresponds to a series of limited sea-level fall and rise leading to evaporite deposition in both the central and peripheral basins; i.e. at variable sea levels. Phase 2 (*i.e.* the peak of the MSC) is characterized by a large sea level drop, evaporite deposition in the central basins, and subaerial erosion of the margins. In the diachronous scenarios evaporites were only deposited in the peripheral basins during phase 1 and in the central basins during phase 2.

deep Mediterranean basin[2] (Cita, 1973; Hsü, 1973; Hsü et al., 1973b; Hsü and Bernoulli, 1978; Montadert et al., 1978; Stampfli and Höcker, 1989). Three arguments have been used to strengthen this theory: the tidal nature of the evaporites recovered in all the major basins (Hsü, 1972a,b); the pan-Mediterranean distribution of seismic reflector M that was calibrated with the abrupt contact between the evaporites and the overlying Early Pliocene marls (Ryan, 1973), and the open marine, deep bathyal nature of the pelagic sediments immediately superposed on the evaporites (Cita, 1973). This argument was also supported from studies on products of the marginal erosion coeval with the deep basin evaporites all around the Mediterranean (Barr and Walker, 1973; Chumakov, 1973; Clauzon, 1973, 1974; Cita and Ryan, 1978; Clauzon, 1978; Rizzini et al., 1978; Ryan and Cita, 1978; Clauzon, 1979, 1982; Barber, 1981). In the 1990s, the peripheral Mediterranean basins accessible to field studies were used to constrain the timing of the MSC (Hilgen and Langereis, 1993; Gautier et al., 1994; Krijgsman et al., 1999a; Van Couvering et al., 2000; Lourens et al., 2004). No physical link has been established between these basins and offshore Mediterranean deep basins and evaporites from the deep basins have not been fully sampled or accurately dated. Therefore the timing and the environment of evaporites deposition in the Mediterranean deep basins is still uncertain and controversial.

Two groups of conceptual scenarios are usually referred to (Fig. 1): one that favours a synchronous deposition (at 5.96 Ma) of the first evaporites in all the Mediterranean basins before the huge sea level fall (Krijgsman et al., 1999a; Rouchy and Caruso, 2006), and the second that favours a diachronous deposition of the evaporites through two phases of desiccation (Butler et al., 1995; Clauzon et al., 1996; CIESM, 2008). According to the second scenario, peripheral basins experienced deposition of evaporites from 5.971 Ma (Manzi et al., 2013) to 5.600 Ma after an initial sea level fall (~150 m, phase 1): in this paper, we call these the “1st step evaporites”. Then, from 5.600 to 5.460 Ma (Bache et al., 2012) the Mediterranean deep basins experienced a major sea-level fall (1500 m) and deposition of evaporites in almost completely desiccated environments. In this paper we call them the “2nd step evaporites”. During this second phase (the “peak of the MSC”), the “1st step evaporites” were partly eroded and reworked.

Interpretation of the environmental setting of some basins is also controversial. For example, the Sicilian Caltanissetta Basin has been interpreted as either a deep basin that was subsequently uplifted (Hsü et al., 1973a; Krijgsman et al., 1999a; Rouchy and Caruso, 2006; Roveri and Manzi, 2006; Krijgsman and Meijer, 2008), containing only “2nd step evaporites”, or as a peripheral basin (Brolsma, 1975; Butler et al., 1995; Clauzon et al., 1996; Popescu et al., 2009) containing the “1st step evaporites”. Following the former interpretation, Roveri and Manzi (2006) questioned the existence of a significant (>1000 m) Messinian sea level drawdown and argued in favour of widespread tectonic movements to explain observations all around the Mediterranean. On the other hand Roveri et al. (2008a,b) opted for the occurrence of the two steps of evaporites in Sicily which includes peripheral basins (Calatafimi-Ciminna, Belice, Licodia) and an intermediate basin (Caltanissetta).

In order to clarify the events that affected the Mediterranean basins, we describe the marginal transition from the Gulf of Lions shelf to the Provence deep Basin. Stratal relationships between the subaerial erosional surface, clastic deposits generated by this erosion and evaporites allow us to discuss the mode of deposition of the “2nd step evaporites” and to test a refined scenario with a numerical model.

2. Data and method

The Gulf of Lions (Fig. 2) is weakly deformed by Pliocene and Quaternary tectonics and characterised by a relatively high subsidence rate which continuously created accommodation space (Steckler and Watts, 1980; Bessis, 1986; Burrus, 1989; Rabineau et al., 2005; Bache et al., 2010). This configuration, together with the availability of a large set of seismic reflection data (Fig. 2), has allowed accurate descriptions of the relationship between the Messinian halite and the sedimentary units of the Gulf of Lions margin (Gorini, 1993; Lofi et al., 2005; Bache, 2008; Bache et al., 2009). In this study, conventional and high-resolution seismic reflection data are reviewed and interpreted using the principles of seismic stratigraphy (Vail et al., 1977). The extensive coverage of seismic data enabled an integrated seismic stratigraphy to be developed, with seismic unit identification based on the configuration of seismic reflectors, including reflector continuity and termination. Interpretation and correlation of seismic reflectors has been tied to biostratigraphic and lithostratigraphic data from eleven hydrocarbon exploration wells that sampled Miocene and younger sedimentary cover. Seismic two-way travel-time (TWT)

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[2] According to their geographic respective location, we distinguish (1) peripheral basins characterised by continuous shallow-water conditions in the Messinian and Zanclean (most of them being onshore today), and (2) deep basins where deep marine conditions prevailed except during the peak of the MSC.