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Synchronous onset of the Messinian evaporite precipitation: First Mediterranean offshore evidence

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ABSTRACT

The Messinian Salinity Crisis (MSC) was a major ecological crisis affecting shallow and deep-water settings over the entire Mediterranean basin. However, the evolution of the MSC and its ecological impacts have mainly been explained on the basis of sediments from onshore outcrops. Lack of complete and physically connected records from onshore and offshore settings has inhibited comprehensive understanding of basin behaviour during the MSC. Herein we present a continuous record from an intermediate-depth basin on the Balearic Promontory that comprises late Tortonian–Messinian marls and evaporitic beds from the first MSC phase (i.e., Primary Lower Gypsum-PLG stage). Well-log and biostratigraphic data allow us establishing a large-scale calibration to the astronomical solutions, and to correlate pre-MSC sediments with classical rhythmic successions outcropping onshore. Thickness and characteristic sedimentary patterns observed in the offshore evaporitic records resemble those from marginal PLG sequences. Furthermore, seismic reflectors from a Bedded Unit (BU), which corresponds to an evaporitic interval according to well-to-seismic ties, are correlated with the onshore PLG sequences. This correlation constitutes the first attempt to link well-known marginal sequences with intermediate-depth offshore settings, which have previously only been studied through seismic imaging. Our time-calibration provides direct evidence supporting a synchronous onset of the PLG phase between onshore and offshore settings along the southwestern Balearic Promontory margin. Those BU reflectors, which were positively correlated to the PLG, were likely precipitated offshore the continental shelf at Messinian times. These results suggest that gypsum precipitation and/or preservation was not always limited to 200 m water-depths and could occur in non-silled basins. Finally, we only found a major erosion at the top of the PLG sequences, implying that the MSC drawdown occurred after the precipitation of the onshore lower evaporites. Studied sequences provide new insights into the PLG precipitation/preservation settings, as well as into the land-sea correlations of MSC units, and thus could potentially help refine current MSC models.

1. Introduction

During the latest Miocene, tectonic-driven processes triggered the closure of the Betic and Rifian gateways, which previously connected the Atlantic and the Mediterranean seas. Consequently, seawater exchange between these seas was reduced and Mediterranean waters became increasingly salty, leading to the precipitation of thick evaporite sequences (e.g. gypsum and halite) at different times and depocenters (see Roveri et al., 2014 and the references therein). A giant salt deposit, containing in volume almost 5% of the salt of the world oceans (Ryan, 2008), was formed. This event, known as the Messinian Salinity Crisis-MSC, was rapid (5.97–5.33 Ma; Krijgsman et al., 1999; Manzi et al., 2013) and affected biological (e.g. Kouwenhoven et al., 1999; Sierro et al., 2003), chemical (De Lange and Krijgsman, 2010), and sedimentary processes in the Mediterranean Sea (CIESM, 2008; Roveri et al., 2014). At a global scale, the closure of these gateways would impacted the North Atlantic hydrography, by altering the exchange of water, heat, nutrients, and salt. Hence, it influenced the northern hemisphere's ocean circulation and climate (Rogerson et al., 2012).

Multiproxy studies have demonstrated that the crisis affected the complete Mediterranean basin. Nonetheless, the MSC evolu-

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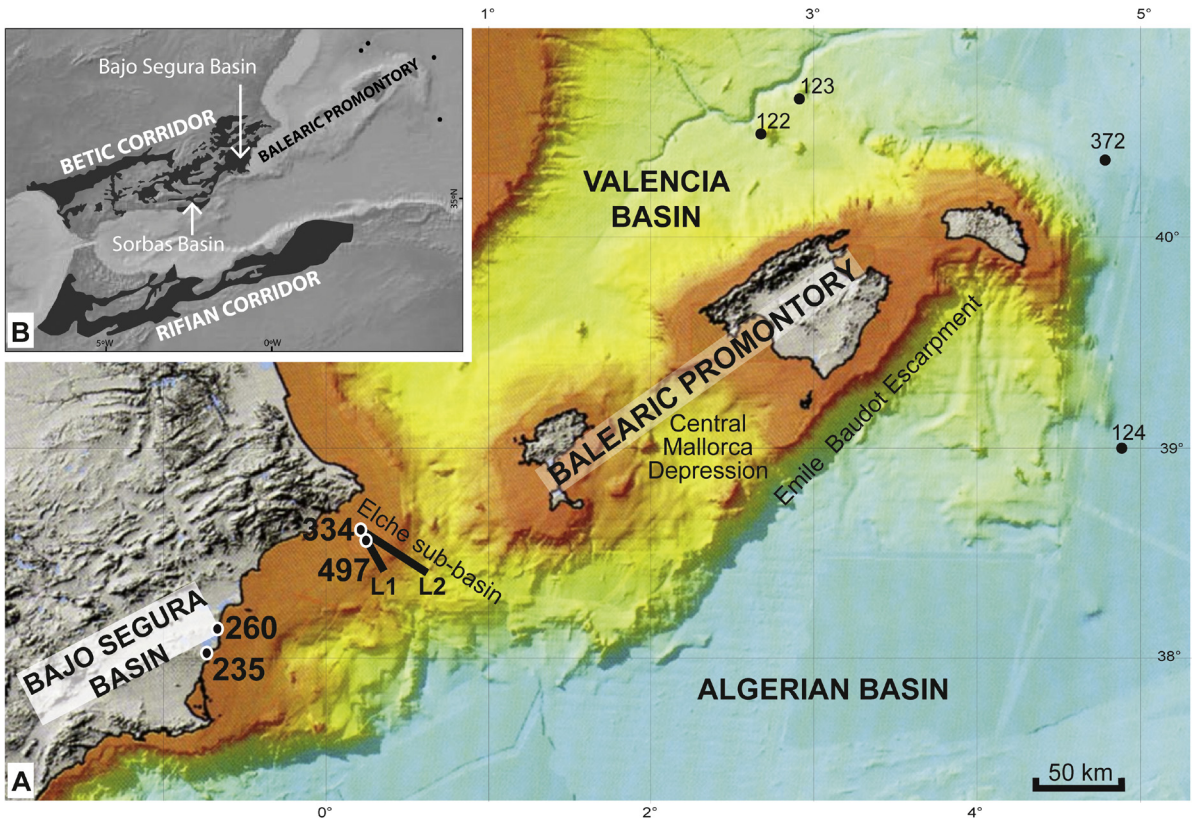

Fig. 1. A) Bathymetric map of the Balearic Promontory modified after Maillard and Mauffret (2013). Numbers indicate studied wells: 235-San Miguel-1, 260-La Mata, 334-Calpe, and 497-Muchamiel. SIMBAD seismic profiles (L1 and L2) shown in Fig. 8 are also located. B) Reconstructed Betic and Rifian gateways based on present-day location of onshore Late Miocene marine sediments. Location of Sorbas and Bajo Segura marginal basins is also shown.

tion has been traditionally explained by using observations and data from uplifted marginal areas. In onshore successions, three MSC-sedimentary units characterised by distinct evaporitic associations, are observed (see CIESM, 2008 and Roveri et al., 2014 and the references therein). These units can be roughly described as: primary lower gypsum (Lower Evaporites), followed by halite with clastic gypsum, ending in either brackish deposits (*Lago Mare*) or gypsum sequences (Upper Evaporites). By contrast, Messinian offshore stratigraphy mostly relies on seismic profiles. Three MSC-related seismic units have been identified in the deep Western Mediterranean basins (i.e., the Messinian trilogy of Montadert et al., 1970) based on their seismic facies and geometrical arrangements. This trilogy is formed by: the Lower Unit, the Mobile Unit consisting mainly of halite, and the Upper Unit that was partially drilled during some DSDP/ODP legs (Ryan et al., 1973; Montadert et al., 1970). However, the age and/or nature of these units endure unknown. Additionally, a fourth seismic unit, known as the Bedded Unit (BU), was also identified in some disconnected intermediate-depth basins (Driussi et al., in press; Lofi et al., 2011; Maillard et al., 2014). As a result of these different datasets, stratigraphic correlations between onland sequences and offshore intermediate-depth, and between intermediate and deep-basin seismic records are challenging. Establishment of land-sea correlations has been hampered by the lack of complete and geometrically connected stratigraphic records. Consequently, scenarios explaining the causes, progression and timing of the MSC remain controversial, as they are largely untested.

In this work, we focused on the first phase of the crisis, known as the Primary Lower Gypsum-PLG stage (5.971–5.61 Ma) (CIESM, 2008; Lugli et al., 2010; Manzi et al., 2013). This phase has been characterised by hypersaline conditions, causing the precipitation of gypsum at shallower settings (<200 m) and aplanktic dolomites or black shales at deeper settings (<1000 m) (e.g. Dela Pierre et al., 2012; Hilgen and Krijgsman, 1999; Manzi et al., 2007; Lugli et al., 2010). Gypsum precipitation has been linked to precession-driven changes in climate (Krijgsman et al., 1999; Lugli et al., 2010; Manzi et al., 2013), and it is generally interpreted as only occurring at interconnected but silled subbasins with restricted water circulation (Lugli et al., 2010). High-resolution chronostratigraphic studies in pre-crisis sediments have indicated that the onset of this first stage was synchronous around the Mediterranean basin (Krijgsman et al., 1999).

Through the integration of biostratigraphic, logging and seismic data, here we investigated drilled-sediments from the Balearic Promontory that were recently associated with onshore PLG successions (Driussi et al., in press). We determined the timing of the PLG onset and established a reliable chronostratigraphic framework for offshore intermediate-depth settings (<1000 m) in the promontory, which allowed detailed correlations with Messinian onland shallow-water records (<200 m). Studied records have experienced relatively little syn- and post-MSC deformation and include a complete pre-MSC record directly connected to the Betic Corridor (Fig. 1). Thus, they were successfully time-calibrated, laterally connected with outcropping onshore sections, and their seismic expression was further extended basinwards. We demonstrated that PLG evaporites are present at current depths of up to 1000 mbsl along the promontory, and that they correspond to the seismic Bedded Unit reflectors from the southwestern promontory margin. Finally, by comparing our sequences with those from marginal onshore basins (Sorbas and Bajo Segura basins; Fig. 1A), we reconstructed the geological evolution of the southwestern Balearic Promontory margin before and during the PLG stage and discussed implications for the MSC. Comprehensive analyses on