Earth and Planetary Science Letters 286 (2009) 139–157

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

Messinian erosional and salinity crises: View from the Provence Basin (Gulf of Lions, Western Mediterranean)

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ARTICLE INFO

Article history:
Received 28 November 2008
Received in revised form 17 June 2009
Accepted 18 June 2009
Available online 19 July 2009

Editor: M.L. Delaney

Keywords:
Messinian
Salinity Crisis
Gulf of Lions
Mediterranean
Provence Basin
Miocene
detrital deposits
erosion

ABSTRACT

Though the late Miocene "Messinian Salinity Crisis" has been intensely researched along the circum-Mediterranean basins, few studies have focused on the central part of the Mediterranean Basin and, especially, the pre-salt deposits. To improve our knowledge of the Messinian events, it is imperative to better understand this domain. In this study, we provide a more complete understanding of this central domain in the Provence Basin. We were able to recognize: a) thick marine detrital series (up to 1000 m) derived from the Messinian subaerial erosion which is partly prolongated in the distal part by b) a thick unit of deep marine deposits (up to 800 m) prior to the evaporites; c) a thick presumed alternation of detritals and evaporites (1500 m) below the mobile halite; and d) a two-step transgression at the end of the Messinian. Spatially, we document the eroded shelf to the deep basin (and from the western to the eastern parts of the Gulf of Lions), and temporally, we extend the interpretations from the early deposition of detritic sediments to the final sea-level rise. The results provide a new basis for discussion not only for the development of the Messinian Salinity Crisis but also for the reconstruction of the subsidence history of the Provence Basin.

1. Introduction

The reduced inflow of Atlantic Ocean water through the Betic and Rifian corridors (Fig. 1) at the end of the Miocene, together with a high evaporation rate, led to a significant lowering of the Mediterranean Sea's base level and gave rise to one of the most prominent episodes of the Sea's history, known as the "Messinian Salinity Crisis". This Salinity Crisis continues to raise questions and arouse interest. First, because of the wide geographical extent of the extreme environment, the Messinian gave rise to one of the largest evaporite basins known (2.5 million km^2), comparable in size to the North Sea Permian basins (Ziegler, 1982). Its comparatively younger (Neogene) age also makes it much more accessible to analysis and modelling than older and deeper large known basins. Second, the volume of the Messinian evaporite series is greater than 1 million km^3 in the Mediterranean Basin (Ryan, 1973). The Messinian (evaporitic and erosional) events are also distinctive in that they occurred in a relatively brief period of ~0.63 My (Hilgen et al., 2007) and during the history of an oceanic-type basin which is at least 15 million years old.

A supply of oceanic water to the basin is necessary to explain the thickness of the evaporite layer. In view of the absence of connections with the Indian Ocean, the history of the eastern Mediterranean Basins (e.g. Tyrrhenian, Ionian) is linked intimately to the western basin. Within the western Mediterranean Sea, the Gulf of Lions is exceptional in that its sedimentary strata have not been deformed. In addition, the Gulf of Lions is characterized by relatively constant subsidence with continuous accommodation space for sediment accumulation. This margin is also characterized by a gentle slope, which prevents major remobilization and gravitational movements. This configuration, together with the availability of a vast data base, enables us to describe full geometries of the stratal patterns of Miocene series (from the intensely eroded geomorphologies on the shelf to the well preserved successions in the basin).

Previous studies have focused on "marginal" or "peripheral" basins (mainly present-day onshore areas) rather than on the "central" basins (present-day offshore areas). The central basins are relatively of wide extent and contain thick evaporitic sequences, while marginal basins are much smaller with reduced evaporitic sequences (Fig. 1). These basins have also been studied with two very different approaches due

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0012-821X/$ – see front matter
doi:10.1016/j.epsl.2009.06.021

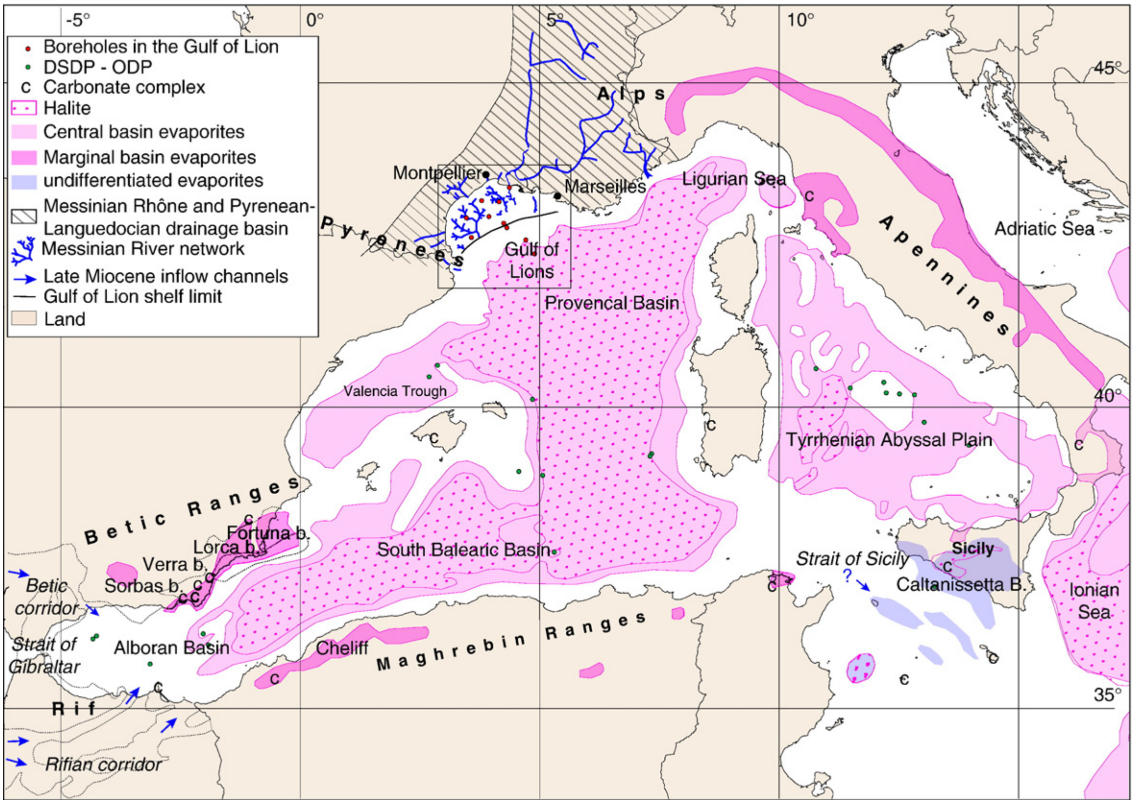

Fig. 1. Location of the Messinian evaporite series (halite and other evaporites) in the Western Mediterranean (modified for the Gulf of Lions from Montadert et al., 1978; Rouchy and Caruso, 2006) and the area drained by the Messinian rivers in Southeastern France (hachured). The Late Miocene Betic and Rifian corridors (dotted line) are taken from Martin et al., 2001. The study area is outlined in black.

to their accessibility: outcrop studies, and some mines and boreholes in marginal basins and remote geophysical techniques in the central basins. So far the central Mediterranean Basin has been poorly known, due to its relative inaccessibility and lack of integration of available data.

2. Overview of previous works

Pioneer works based on field studies described a huge incision in the Rhône River valley at the end of Miocene (Fontannes, 1882; Depéret, 1890, 1893; Denizot, 1952). The isolation of the Mediterranean at that time, a drop in sea level, the subsequent invasion of the sea in the fluvial network in earliest Pliocene and the idea that a salinity crisis could have occurred were proposed very early (Denizot, 1952; Ruggieri, 1967). The development of reflection profiling techniques and increasing exploration established the existence of a mobile layer capable of generating diapirs beneath the floor of most of the central basins of the Mediterranean Sea (Alinat and Cousteau, 1962; Hersey, 1965; Menard et al., 1965; Glangeaud et al., 1966; Ryan et al., 1966; Leenhardt, 1968; Mauffret, 1970; Montadert et al., 1970; Auzende et al., 1971; Ryan et al., 1971). The origin of this layer was largely interpreted as related to salt deposition. However, different interpretations were proposed for the age of salt deposition and its disposition (Glangeaud et al., 1966; Cornet, 1968; Ryan, 1969; Mauffret, 1970; Montadert et al., 1970). Using new and high quality seismic data acquired in the Mediterranean Basin in 1970, Auzende et al. (1971) proposed that the salt was late Miocene in age, following earlier suggestions from Denizot (1952) and Ruggieri (1967). At the same time, the salt was cored during Leg 13 of the Deep Sea Drilling Project in 1970 along with its cover of gypsum, anhydrite, lacustrine mud and marls with clastics reworked from the margin. This layer was dubbed the “Upper Evaporites” by the Leg scientists. All these deposits were indisputably dated and interpreted for the first time as deep-basin products of the Messinian Salinity Crisis (Ryan et al., 1970; Hsü, 1972b; Hsü et al., 1973b). Two models, both based on the deposition of evaporites in shallow water depth were proposed and initiated a heated debate in the scientific community: the “shallow water, shallow-basin desiccation model” (Nesteroff, 1973); and the “desiccated, deep basin model” (Hsü, 1972b; Cita, 1973; Cita and Ryan, 1973; Hsü, 1973; Hsü et al., 1973a; Ryan, 1973).

The first model suggests the existence of a shallow basin (several hundred meters deep) before the Salinity Crisis. This model envisioned vertical tectonic movement during the Pliocene that would have deepened the basin after the crisis (Bourcart, 1962; Pautot, 1970; Auzende et al., 1971; Burollet and Byramjee, 1974; Stanley et al., 1974; Rouchy, 1980, 1982). But considering that different basins that make up the Mediterranean are of different ages—some much older (such as the Ionian Sea), others much younger (such as the Tyrrhenian Sea)—this Alpine tectonic model soon became obsolete. The second model suggests the existence of a deep basin (over 1500 m deep) before the Messinian crisis (Argand, 1924; Cita, 1973; Hsü, 1973; Hsü et al., 1973b; Hsü and Bernoulli, 1978; Montadert et al., 1978; Stampfli and Höcker, 1989) and a sea-level drop of around 1500 m. Three arguments were 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).

The deep basin model could also be defended by kinematic and geodynamic considerations: such a basin, opened by the rotation of a microcontinent during the Oligocene time (at around 30 My) in the general framework of African–European convergence (Smith, 1971;