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On the late Miocene closure of the Mediterranean–Atlantic gateway through the Guadix basin (southern Spain)

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ABSTRACT

The late Miocene Mediterranean–Atlantic connection through southern Spain is generally thought to have closed during the late Tortonian, but accurate constraints on palaeobathymetry, shallowing rates and closure age are still lacking. We present integrated biostratigraphic (planktonic, benthonic foraminifera and mammals) and magnetostratigraphic results from the marine to continental La Lancha section of the Guadix Basin, refining the chronology for the Miocene–Pliocene sedimentary sequences of this basin that occupied a central position in the marine gateway. In addition, we perform palaeobathymetric analyses on the marine sedimentary sequence to reconstruct sea level fluctuations and vertical motions. Deposition of the Lower Marine Unit took place between 8.1 and 7.85 Ma with accumulation rates of ~1 m/kyr. A rapid shallowing from palaeodepths of 500–300 m to a depth of 300–200 m took place at ~8.0 Ma coinciding with a decrease in downslope transport. Surprisingly, no shallowing trend has been observed towards the unconformable contact with the Transitional Unit, which was deposited in a shallow (~90 m) marine environment. The youngest open marine marls are still indicative for a palaeodepth of >200 m. This leads to the conclusion that fully marine environments in Guadix persisted until at least 7.85 Ma. The palaeomagnetic polarity pattern of the Upper Continental Unit, in combination with the presence of the murid *Paraethomys meini* in the basal part of this sequence, indicates that the entire continental unit at La Lancha is attributed to the latest Messinian–Zanclean time. This age is in strong contradiction with previous correlations to the late Tortonian. Consequently, we conclude that a major hiatus of at least 2 Myr, comprising most of the Messinian stage, is present in the Guadix basin. Therefore a late Tortonian closure age of the Mediterranean–Atlantic gateway through Guadix has not been confirmed by our results, so that the possibility of a Messinian gateway through southern Spain cannot be completely ruled out.

1. Introduction

The opening and closure of oceanic gateways is critical in controlling palaeoceanographic circulation patterns. These circulation patterns are driven by a number of interactive factors, but the most important are the climate and bathymetry of the region (e.g. Cramp and O'Sullivan, 1999). In the present-day Mediterranean situation, the loss of water by evaporation is more than double the gain by precipitation and run-off. This inequality drives the circulation across much of the basin and produces an outflow of saline warm water at depth across the sill of Gibraltar and a surface inflow of less saline water. Restricting the gateway could eventually block this outflow, which would significantly alter the Mediterranean circulation patterns and hence its palaeoenvironmental conditions, ultimately leading to evaporite precipitation (e.g., Krijgsman et al., 1999a; Krijgsman and Meijer, 2008).

In late Miocene times the Mediterranean was connected to the Atlantic Ocean by marine gateways through northern Morocco and southern Spain (e.g. Benson et al., 1991; Betzler et al., 2006; Fig. 1). The increasing number of studies in basins, particularly of the Betic corridor, enabled a more detailed palaeogeographic reconstruction of the marine passages, leading to the recognition of diachronous closure of individual branches of the marine connection (Fig. 1b). Overall, tectonic activity in the Gibraltar region, related to Africa–Europe convergence, increased during the late Tortonian and these marine gateways became progressively restricted and finally closed in the course of the latest Miocene (e.g. Wijermars, 1988; Gutscher et al., 2002; Duggen et al., 2003). As a consequence, the Mediterranean became isolated from the Atlantic, which resulted in dramatic changes in palaeoceanographic and palaeoenvironmental conditions eventually leading to massive

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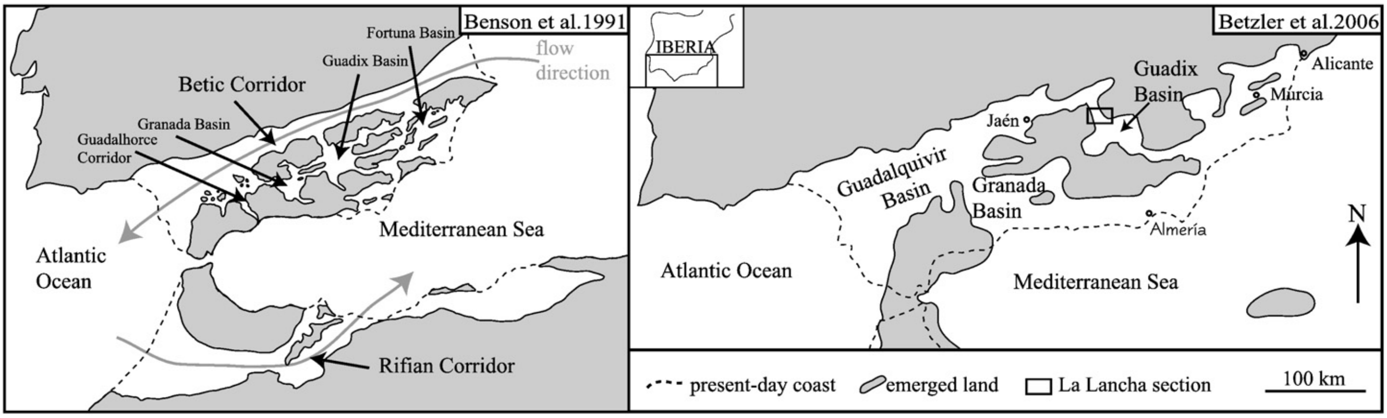

Fig. 1. Palaeogeographic reconstructions of the Mediterranean–Atlantic marine passages through the Betic and Rifian corridor during the late Tortonian: (a) adapted from Benson et al. 1991 and (b) adapted from Betzler et al., 2006.

evaporites throughout the Mediterranean during the so-called Messinian salinity crisis (MSC; Hsü et al., 1973; Hsü et al., 1978). Recently, the scientific debate on MSC models converged to a scenario that required Mediterranean–Atlantic water exchange to remain effective until the end of Lower Gypsum formation, astronomically dated at 5.6 Ma (e.g. Roveri et al., 2006; Krijgsman and Meijer, 2008). The Betic Seaway through southern Spain, however, is commonly thought to have closed in the late Tortonian at ~7.8 Ma (Soria et al., 1999; Betzler et al., 2006), culminating in evaporitic conditions in the internal basins of the eastern Betics during the Tortonian salinity crisis (Krijgsman et al., 2000; Garcés et al., 2001). A remaining southern branch through the Guadalhorce region was suggested to have persisted during the early Messinian (Martin et al., 2001), but closing at ~6.8 Ma and supposedly triggering reef growth in south Betic basins like Sorbas (Martin and Braga, 1994; Braga and Martin, 1996). The last marine sediments in the central Rifian corridor were dated at ~6.8 Ma, based on integrated stratigraphic data from the central Taza–Guercif basin (Krijgsman et al., 1999b). An early Messinian age for the closure of the Rifian Corridor is in agreement with palaeoenvironmental results from the Mediterranean margin near Melilla indicating the presence of a tropical diatom assemblage from an age of 6.6 Ma onward (Cornée et al., 2002; Van Assen et al., 2006). The Strait of Gibraltar is generally thought to have originated at the beginning of the Pliocene, refilling the Mediterranean after the Messinian salinity crisis (Hsü et al., 1973; Blanc, 2002). Consequently, we face an apparent controversy in stratigraphic data suggesting that Mediterranean–Atlantic connections must have persisted until 5.6 Ma to allow accumulation of kilometres thick salt units in the Mediterranean, while at the same time all potential seaways to the Atlantic seem to have been closed.

To determine the precise age of gateway closure has proven to be rather difficult, because when the seaway emerges through tectonic uplift, depositional environments will become very shallow and the youngest marine deposits may even become subject to erosional processes (e.g. Hüsing et al., 2009a). Integrated biostratigraphic and magnetostratigraphic dating techniques are required, although both techniques are also problematic in very shallow coastal sandy deposits. In this study we try to get a more precise chronology for the marine to continental evolution of the Guadix Basin, which was located in the central Betic Seaway during the Tortonian (Soria et al., 1999). By combining biostratigraphic studies on marine foraminifera and continental mammal faunas with magnetostratigraphic investigations and palaeobathymetric reconstructions we aim to get precise time control on the shallowing rate and closure age of the Betic seaway. The results allow a more detailed correlation to the palaeoenvironmental changes in the Mediterranean that have been accurately determined in a high-resolution time frame through astronomically dated sedimentary sequences of late Tortonian–early Messinian age (Hilgen et al., 1995; Kouwenhoven et al., 2006; Hüsing et al., 2009b).

2. Geological background

The Guadix basin is one of the largest intramontane basins of the Betic Cordillera, which formed after the westward drift and collision of the Alboran block with the Iberian margin (Fig. 2a). It is located in the central part of the cordillera and seals the contact between the Internal and External Betic Zones (mainly Palaeozoic basement and Mesozoic cover, respectively) to the north by the Sierra Nevada massif. The basin evolution was controlled by strike-slip faults trending NW–SE and ENE–WSW, activated under an overall NW–SE compressional regime resulting from continuous convergence between the African and Iberian plates (Sanz De Galdeano and Vera, 1992). The Guadix basin is bounded to the east by the Jabalcón threshold, which separates it at present from the Baza basin, but both basins were previously connected and are also known as Guadix–Baza basin.

The overall stratigraphic record of the Guadix basin spans the Tortonian (Soria et al., 1999) to Pleistocene, and can be divided into three major units (Fernandez et al., 1996): a Lower Marine Unit, a Transitional Unit and an Upper Continental Unit.

The Lower Marine Unit constitutes a transgressive sequence corresponding to a phase of relative sea-level rise. Sediments onlap a very irregular palaeotopography, leading to large variations in thickness, from tens of meters to maximum accumulated thickness of 500 meters in the area near Dehesas de Guadix. Most representative deposits are bioclastic calcarenites along the margins and marls towards the center of the basin. The upper part of the marine stage represents a sea-level highstand, recording a change of sedimentary polarity from retrogradation to progradation of the southern margin carbonate platforms (Soria et al., 1998; Soria et al., 1999; Betzler et al., 2006).

The marine sedimentation stage in the Guadix basin is also recognized in the Granada, Fortuna and Lorca basins (see Figs. 1 and 2). These basins were interconnected during the Tortonian forming the so called Betic corridor, a marine passage between the Atlantic and Mediterranean water masses. In this palaeogeographic context, the intramontane basins of the central Betics (Granada, Ronda and Guadix) were regarded as the northern extension of the Alboran basin, which in the late Miocene occupied a much wider area than present (Comas et al., 1992).

The Transitional Unit represents a regression that is widely recognized in the Betic domain, prior to the closure of the marine seaway. The Guadix basin records the emergence of the marginal areas while deposition of shallow carbonate platforms and minor