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Research paper

The late Miocene Mediterranean-Atlantic connections through the North Rifian Corridor: New insights from the Boudinar and Arbaa Taourirt basins (northeastern Rif, Morocco)

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ABSTRACT

New data from the Neogene Boudinar and Arbaa Taourirt basins (northeastern Morocco) provide constraints on the late Miocene evolution of the North Rifian Corridor. The chronostratigraphy of these basins is clarified on the basis of biostratigraphic (planktonic foraminifers, calcareous nannoplankton) and radio-isotope ages. Marine sedimentation in the Boudinar Basin began during the early Tortonian at ~10 Ma and persisted until the late-early Messinian at ~6.1 Ma. In the Arbaa Taourirt basin, it occurred between the late Tortonian and the earliest Messinian. Paleoenvironmental data (benthic foraminifera and pollen grains) record a major drowning in association with extensive tectonism in the Boudinar basin during the early Messinian (~7.2 Ma). Synchronously, there was a major sedimentological change in the Arbaa Taourirt basin with progradation of conglomerates and sandstones over late Tortonian marls. Large-scale cross-bedded sandstones indicate paleo-currents flowing from the Atlantic Ocean toward the Mediterranean Sea. During the late-early Messinian, a shallowing trend occurred, culminating with the progradation of reefal carbonates. Our findings indicate that the North Rifian Corridor opened at ~7.2 Ma ensuring Atlantic-Mediterranean connections. The Corridor was progressively restricted during the late-early Messinian with complete closure by ~6.1 Ma. The results of this study thus question existing hypotheses for the timing and nature of Atlantic-Mediterranean connections during the late Messinian.

1. Introduction

The Betic and Rif Chains started to build during the Oligocene as a result of the convergence between Africa and Europe (Jolivet et al., 2006; Chalouan et al., 2008). During the late Miocene, several marine gateway systems connected the Mediterranean Sea with the Atlantic Ocean through the Betic and Rif Chains, in southern Spain and northern Morocco, respectively (Benson et al., 1991; Krijgsman et al., 1999a; Martín et al., 2001, 2009, 2014) (Fig. 1A). The Rifian marine gateway comprises two corridors, the North Rifian Corridor and the South Rifian Corridor (Fig. 1A). Tectonic uplift processes caused by plate tectonics (Krijgsman et al., 1999a; Gutscher et al., 2002; Duggen et al., 2003; Garcia-Castellanos and Villaseñor, 2011), combined with climatic and eustatic changes (Krijgsman et al., 1999a; Hilgen et al., 2007; Manzi et al., 2013; Pérez-Asensio et al., 2012a; Pérèz-Asensio et al., 2012b), may have promoted the progressive restriction and the closure of these corridors. The closure of marine gateways isolated the Mediterranean Sea from the Atlantic Ocean, leading to the precipitation of thick evaporites in the Mediterranean Sea. This event, known as the Messinian Salinity Crisis (MSC, Hsü et al., 1973; Ryan et al., 1973), occurred between 5.97 Ma and 5.33 Ma (Gautier et al., 1994;

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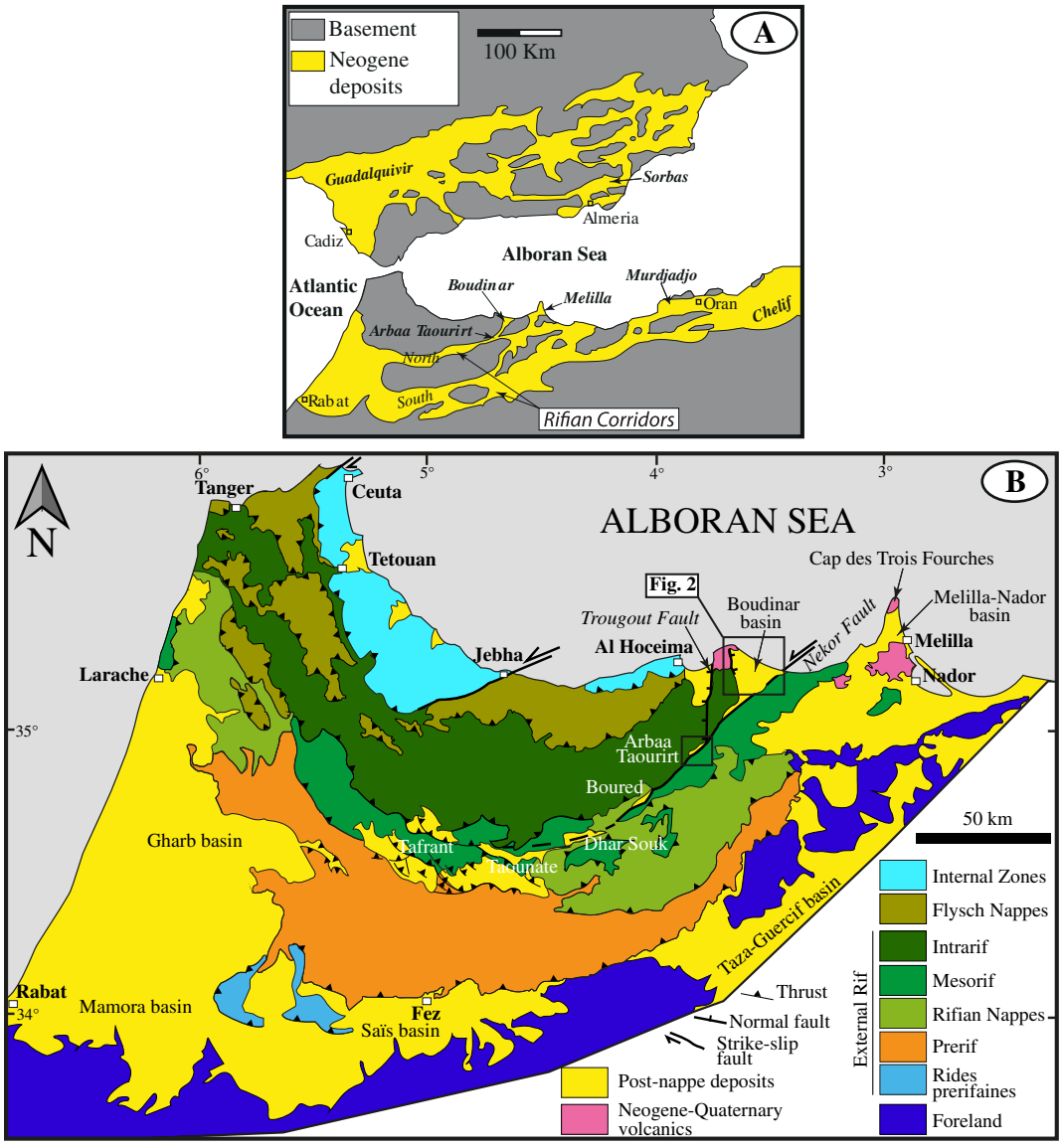

Fig. 1. A) Distribution of the Tortonian-Messinian basins around the Alboran Sea (modified from Esteban, 1996). B) Structural map of the Rif Chain and location of the post-nappes basins (Tafrant, Taounate, Dhar Souk, Boured, Arbaa Taourirt and Boudinar basins). Modified from Suter (1980) and Jolivet et al. (2003).

Krijgsman et al., 1999b; Manzi et al., 2013; Roveri et al., 2014). On the Moroccan margins of the Mediterranean, the witness of the MSC is a subaerial erosional surface (Messinian Erosional Surface, MES) capped by latest Miocene to Zanclean, continental to marine deposits (e.g., Cornée et al., 2014, 2016). The timing of the different openings and closures of these corridors is still subject to significant uncertainties (Benson et al., 1991; Martín and Braga, 1994; Krijgsman et al., 1999a; Martín et al., 2001; Kouwenhoven et al., 2003; Dayja et al., 2005; Van Assen et al., 2006; Hüsing et al., 2010, 2012; Martín et al., 2014; Flecker et al., 2015). During the late Tortonian–Messinian, the Rifian Corridors were the most important passageways connecting the Mediterranean with the Atlantic (Fig. 1A). The intramontane North Rifian Corridor extended between the Boudinar and Gharb basins and the South Rifian Corridor comprised the Melilla-Nador, Taza-Guercif, Saïs and Mamora basins (Fig. 1B). Abundant data are available from the South Rifian Corridor. In the Taza-Guercif basin, the oldest marine sediments marking the opening of the corridor were deposited at ~8 Ma and this passageway between the Mediterranean and Atlantic restricted between 7.2 and 6.1 Ma (Krijgsman et al., 1999a). Moreover, in the Taza-Guercif basin, Nd isotope data have shown that these connections were interrupted at the eastern side of the basin at around 7.2 Ma but persisted elsewhere (Ivanović et al., 2013). On the contrary, data from the North Rifian Corridor are scarce. Only biostratigraphic data of Wernli (1988) are available from the intramontane basins (Taounate, Dhar Souk, Boured and Arbaa Taourirt). In the Boudinar basin, finally, some information is available but contradictory (Guillemin and Houzay, 1982; Wernli, 1988; Barhoun and Wernli, 1999; Azdimousa et al., 2006). Consequently, the timing of opening and closure of the North Rifian Corridor remains unknown.

In this paper, we study the evolution of the North Rifian Corridor, based on a detailed analysis of two key basins directly related to the Mediterranean Sea: the Boudinar and Arbaa Taourirt basins. We provide a refined chronostratigraphic framework of the deposits outcropping in these basins, based on biostratigraphic (planktonic foraminifera, calcareous nannoplankton) and radio-isotope ages. These new data, combined with paleoenvironmental (benthic foraminifera and pollen) and sedimentological data, allow us to reconstruct the late Miocene history of the Mediterranean-Atlantic connections through the North Rifian corridor. As the other Atlantic-Mediterranean connections in Morocco and Spain are well constrained, it is crucial to improve the knowledge of the North Rifian Corridor for establishing the timing of the isolation of the Mediterranean from the Atlantic. Indeed, it has