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Kinematics of Jurassic ultra-slow spreading in the Piemonte Ligurian ocean

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ABSTRACT

The geological record of the western and northern Mediterranean region (Apennines, Alps, Carpathians) contains relics of an ocean basin of Jurassic age known as the Piemonte–Ligurian (PL), Alpine or Alpine Tethys ocean. We here reconstruct the age, direction and amount of extension in the PL basin by analyzing the differences in spreading rates based on marine magnetic anomalies and fracture zones in the Central Atlantic ocean between Africa and North America, and the North Atlantic Ocean between Iberia and North America. The difference in spreading rate must have been accommodated between Iberia and Adria, which we assume to be rigidly attached to the African plate in the late Jurassic. We compute a maximum of ∼450 km of WSW-ENE extension between Iberia and Africa, largely between ∼170 and ∼150 Ma. Relative Adria (Africa)–Europe motion predicts up to 670 km of extension at the longitude of the western Alps – distributed over the PL and Valaisan basins – decreasing to ∼315 km along the easternmost boundary of the PL basin formed by the Tornquist–Tesseyre line. We note that the Africa–Europe plate boundary in the late Jurassic was probably not discretely localized along the Tornquist–Tesseyre line, but distributed over several fault zones including the Severin oceanic basin to the west of the Moesian platform; the 315 km of PL extension in the east should hence be considered a maximum. It is unknown to what extent PL extension was accommodated by genuine ocean spreading, but full spreading rates in the western PL basin were slow, no more than 20 mm/yr. This ultraslow spreading is consistent with characteristics of western Mediterranean ophiolites, including exposure of upper mantle rocks at the sea floor, the alternation of volcanic and avolcanic segments, and the petrologic features of the pertinent magmas and peridotites.

1. Introduction

Marine geophysical studies over the last few decades and increasing accuracy of the geomagnetic polarity timescale (GPTS) have allowed improved reconstructions of plate motions with time. This invites attempts to use these data to reconstruct kinematically linked oceanic basins that have since been involved in subduction and orogeny. The Piemonte–Ligurian (PL) basin that once occupied the western and northern Mediterranean region was at least in part oceanic and is now represented by (ultra)mafic ophiolite fragments preserved in the Alpine belts of e.g. the Ligurian Apennines, Corsica, Alps, and the Carpathians. It was formed in Jurassic–Cretaceous times in response to the progressive opening of the central Atlantic and the concurrent southeastward motion of Africa relative to North America and Eurasia (e.g. Frisch, 1979, Fig. 1a and b). These motions were transferred eastward along a major transform structure now preserved as the (Newfoundland-) Azores – Gibraltar Fracture Zone (AGFZ) and differential motion of Africa with its Adriatic promontory relative to Iberia led to rifting and ocean spreading in the PL domain east of Iberia (Frisch, 1979; Frank, 1987; Stampfli, 1993; Schmid et al., 2008; Handy et al., 2010; Gaina et al., 2013; see Fig. 1a, b). Rifting and subsequent ocean spreading in the Central Atlantic gradually propagated northward into the North Atlantic between North America and Iberia, at the expense of spreading in the PL domain (Fig. 1c).

In this study we address the kinematics of extension in the PL domain. We wish to estimate the size of the PL ocean at the end of its extension, as well as the associated spreading rates through time as they resulted from differential Africa–Iberia motion. The size of the PL ocean is clearly relevant for any Late Mesozoic, early Alpine paleogeographic reconstruction, while spreading rates during oceanization are important to estimate the thermal state of the pertinent oceanic lithosphere and inherent dynamic consequences. We use our results to develop a 'simplest scenario' plate boundary evolution of the northern African plate that may serve as a baseline model for Mediterranean plate reconstructions. Our kinematic analysis assumes that since onset of the opening of the Atlantic

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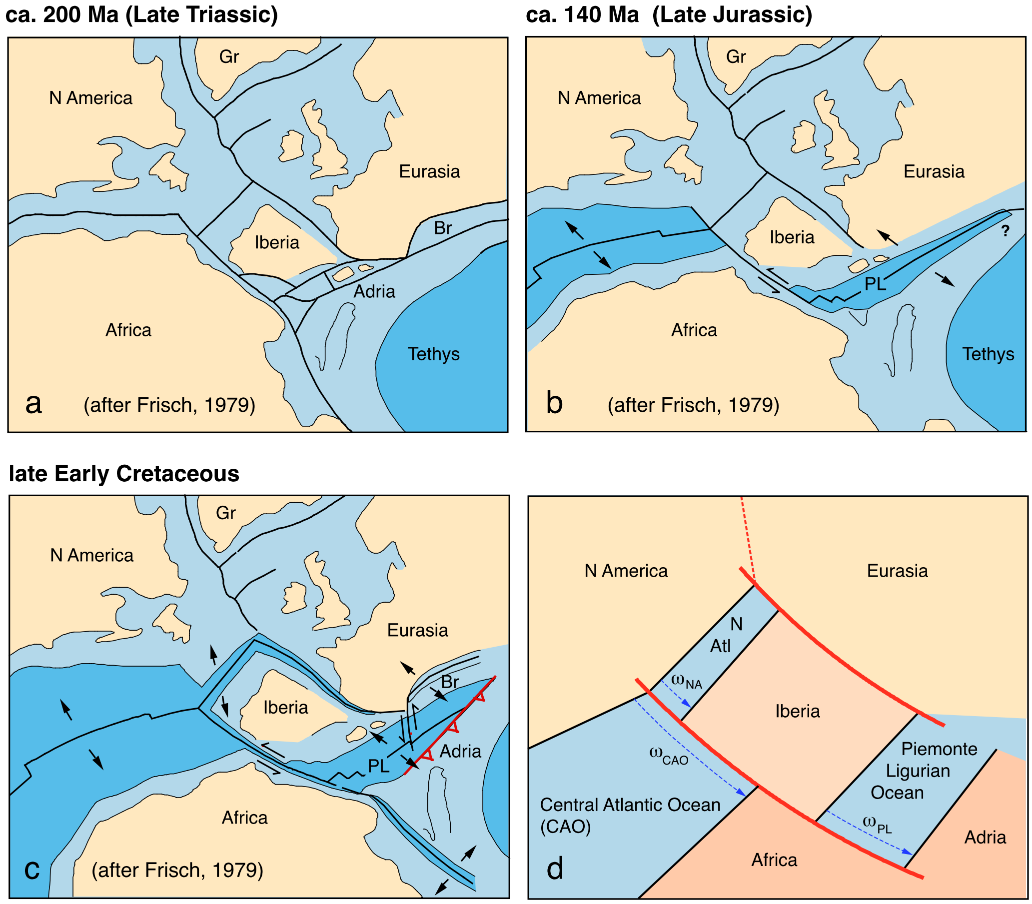

Fig. 1. Plates and plate motions involved in the opening of the PL Ocean, adapted from Frisch (1979): (a) plate geometry in Late Triassic times, (b) opening of the central Atlantic and simultaneous opening in the PL domain (PL), (c) propagation of breakup into the northern Atlantic and onset of Iberia rotation, (d) schematic representation showing how opening of the PL ocean is kinematically linked to Africa and Iberia motions. For further explanation see text.

ocean, the Adriatic promontory has been fixed relative to Africa, i.e. that the oceanic crust of the eastern Mediterranean basin that separates Adria from Africa predates the early-mid Jurassic (Rosenbaum et al., 2002, 2004; Frizon de Lamotte et al., 2008; Gallais et al., 2011; Speranza et al., 2012). GPS data show that Adria is slowly moving relative to Africa today (d'Agostino et al., 2008) and based on geological (e.g. Ustaszewski et al., 2008; Handy et al., 2010; van Hinsbergen and Schmid, 2012) and paleomagnetic data (Channell et al., 1979; Tozzi et al., 1988; Marton and Nardi, 1994; Marton et al., 2011), various and in part contrasting scenarios have been proposed for Cretaceous or Cenozoic motion of Adria relative to Africa. In particular, to accommodate kinematic interpretations of the Alps, Handy et al. (2010) proposed that Adria underwent significant extension relative to Africa in the Paleogene, followed by Neogene subduction between Africa and Adria (Apulia). We note that the resulting position of Adria versus Africa in pre-Cenozoic times inferred by Handy et al. (2010) does not differ from our proposed fixed Adria position with respect to Africa since the Middle Jurassic. Paleomagnetic data from in particular Apulia (southeastern Italy) have been used to infer no rotation of Adria versus Africa (Channell et al., 1979), ∼20° clockwise late Neogene rotation (Tozzi et al., 1988) or ∼20° counterclockwise rotation (Marton and Nardi, 1994). These contradicting scenarios may affect the position of Adria relative to Africa in our reconstructions somewhat, and may hence change the shape of the PL ocean in our reconstructions, but because all postulated Adria–Africa relative motions post-date the time window of interest here, these motions do not affect the amount of extension accommodated in, or the age and rate of, opening of the PL ocean.

Fig. 1d serves to illustrate our approach. The magnitude and rate of extension leading to oceanization in the PL domain should balance the differential motion of Africa and Iberia, where the motion of Africa with respect to N America exceeds that of Iberia. In a description with one single pole for the rotations of Africa and Iberia it follows that for the angular rotation rate in the PL domain:

$$\omega_{PL} = \omega_{CAO} - \omega_{NA}$$

where ω_{CAO} and ω_{NA} are the angular rotation rates in the Central and North Atlantic respectively, associated with the motion of Africa and Iberia relative to North America (Fig. 1d). During the late Early Cretaceous, opening of the Bay of Biscay and progressive rifting and breakup in the North Atlantic (Fig. 1c) induced a ∼35° counterclockwise rotation of Iberia (van der Voo, 1969; Sibuet et al., 2004, in press; Gong et al., 2008; Vissers and Meijer, 2012), and the plate motions started to seriously deviate from the simple model in Fig. 1d. We therefore calculate total reconstruction poles for Africa with respect to Iberia as a basis to reconstruct the development of the PL oceanic domain. For our discussion of the eastern continuation of the PL oceanic domain, we use the rotation poles correcting for pre-drift extension between North America–Eurasia listed in Torsvik et al. (2012).

2. Plates and plate fragments involved

While the opening of the western PL oceanic domain can in essence be described via the interaction of Africa (AFR), N America (NAM) and Iberia (IB), a complete reconstruction of the plate geometry with time requires considering additional plates and plate