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Mesozoic rotation of Iberia: Subduction in the Pyrenees?

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ABSTRACT

Following on paleomagnetic studies in the sixties showing ~35° counterclockwise rotation of Iberia during the Mesozoic, two classes of scenarios have been proposed for the motion history of Iberia which are currently competing. One class infers convergence in the Pyrenees in response to a scissor-type opening of the Bay of Biscay, described by a pole of rotation for Iberia with respect to Europe located within the Bay. The other class of scenarios assumes extensional or transtensional motions in the Pyrenees, compatible with opening of the Bay of Biscay described by a pole of rotation located in northern France. Although plate-kinematic studies over the last decade increasingly support the scissor-type model, geological studies in the Pyrenees have accumulated arguments in favour of an extensional or transtensional regime in the Pyrenean realm.

We perform a detailed plate-kinematic analysis of the Late Jurassic and Cretaceous motion history of Iberia and surrounding plates with respect to Europe. A total of six sea-floor reconstructions in combination with paleomagnetic studies onland allow to recognize four distinct stages. (1) Early rifting and ultraslow spreading since the Kimmeridgean led to the development of an oceanic Neotethys domain north of Iberia. (2) This was followed by ~35° CCW rotation of Iberia during the Aptian, kinematically linked to progressive opening of the Bay of Biscay. (3) Motions in the Bay became stagnant during the Albian till Santonian, followed by the latest stages of spreading in the Bay, and (4) onset of largely Tertiary continental collision between Iberia and Europe eventually leading to the present day structure of the belt.

Our analysis confirms the results of previous studies indicating that extensional or transtensional motions in the Pyrenean realm during opening of the Bay of Biscay and concurrent rotation of Iberia are incompatible with plate-kinematic reconstructions based on sea-floor anomalies. This invites a reappraisal of the geological data. Convergence in the Pyrenean realm during opening of the Bay and rotation of Iberia was accommodated by up to 300 km of subduction of mantle-dominated ocean floor exhumed during the late Jurassic and early Cretaceous. The stagnant stage in the progressive opening of the Bay indicates that convergence in the Pyrenean realm virtually came to a halt during the Albian. We hypothesize that the lithosphere previously subducted during Aptian convergence became gravitationally unstable, leading to asthenospheric upwelling and consequent magmatism and high temperature metamorphism in the overlying European margin now exposed in the North Pyrenean Zone. Aside from these magmatic and thermal effects, an enhanced gravitational potential energy of the remaining lithosphere column underlain by shallow asthenosphere may have led to a stress state allowing belt-parallel extensional deformation. Such a detachment scenario, inspired by plate-kinematic results, may provide an alternative to explain many of the geological data commonly quoted to infer a transtensional or extensional tectonic regime in the Pyrenees during the rotation of Iberia.

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1. Introduction

Opening of the Central and South Atlantic in the early Jurassic and Cretaceous involved breakup of the Pangea supercontinent into Laurasia and Gondwana (Torsvik et al., 2008). Iberia was attached to Europe at that stage and formed part of Laurasia. During the Cretaceous, progressive breakup and spreading in the North Atlantic led to the separation of the Iberian microplate from Eurasia and Africa (Srivastava et al., 1990a; Olivet, 1996; Sibuet et al., 2004a). During this breakup process, the Bay of Biscay opened, leading to approximately 35° of counterclockwise (CCW) rotation of Iberia (Carey, 1958; Bullard et al., 1965; Van der Voo, 1969; Choukroune, 1992; Sibuet et al., 2004a). A recent paleomagnetic study by Gong et al. (2008) has allowed to confine the amount and age of Iberian rotation with respect to Eurasia to 35° CCW during the Aptian, well in line with plate-kinematic studies based on marine geophysical data from the Bay of Biscay (Sibuet et al., 2004a) suggesting 37° CCW rotation between M0 (base Aptian) and anomaly 33o (Campanian) times.

Two competing plate-kinematic end-member models exist to describe the rotation and motion of Iberia with respect to Europe: (1) a scissor-type opening model for the Bay of Biscay, first proposed by Carey (1958) and recently advocated by Srivastava et al. (2000), Rosenbaum et al. (2002) and Sibuet et al. (2004a), and (2) a left-lateral strike–slip opening model, largely inspired by geological observations in the Pyrenees, proposed already by Le Pichon et al. (1970) and Le Pichon and Sibuet (1971), and detailed by Olivet (1996) and followed by e.g., Stampfli et al. (2002), Jammes et al. (2009) and Handy et al. (2010). The first model (Srivastava et al., 2000), which is based on the fit of anomaly M0 identifications across the North Atlantic and Bay of Biscay and constrained by maintaining the direction of motion between the plates along the Azores–Gibraltar fracture zone, infers a total reconstruction pole for the motion of Iberia with respect to Eurasia located in the Bay of Biscay (Fig. 1a). The second model (Olivet, 1996) assumes a total reconstruction pole in northwestern France, farther north of Iberia, to account for dominantly left-lateral strike–slip motion between Eurasia and Iberia, with Iberia moving in a southeasterly direction prior to chron 33o (Fig. 1b). Both models are successful in fitting the shape of the continental margins of the northern and southern Bay of Biscay and of the geomorphological features between Iberia and its adjacent plates. Nonetheless, Sibuet et al. (2004a) argue that the model of Srivastava et al. (2000) fits the M0 better and provides a more robust reconstruction. CCW rotation of Iberia associated with a scissor-type opening of the Bay of Biscay also poses a problem, however. The Pyrenean basins, formed during the Cretaceous on the margins of Iberia and Eurasia, seem genuinely extensional basins, and a scissor-type opening of the Bay of Biscay inevitably leads to large-scale convergence in the Pyrenean domain. This inconsistency between plate-kinematic results based on marine geophysical data and the

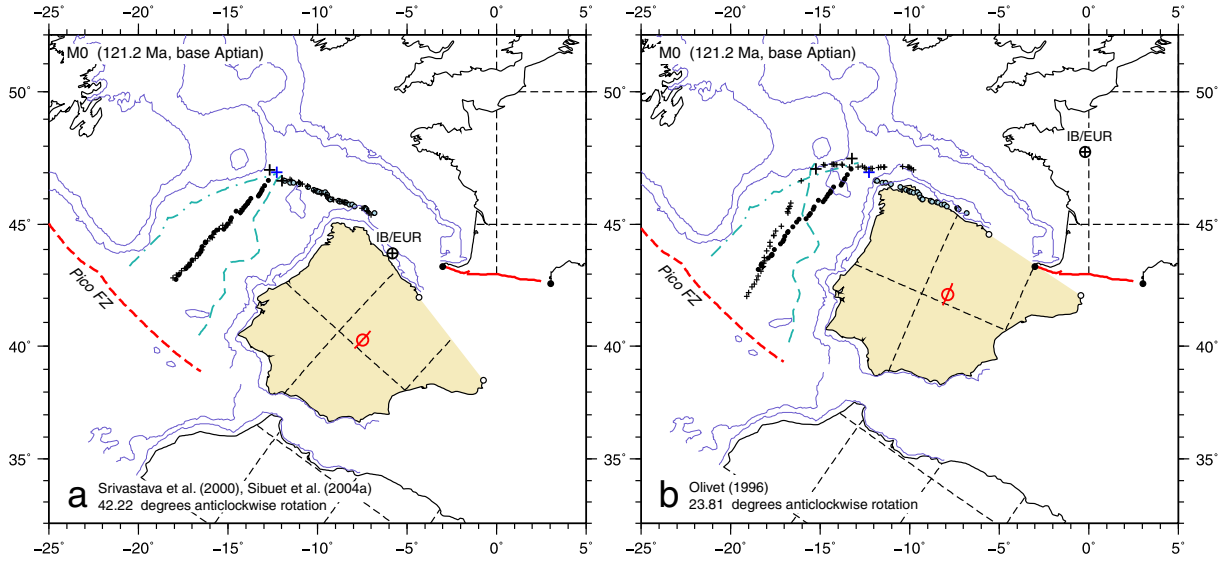

Fig. 1. Reconstructions for Iberia and surrounding plates relative to Europe for chron M0 (121.2 Ma, base Aptian), (a) according to Srivastava et al. (2000) and Sibuet et al. (2004a), and (b) according to Olivet (1996). Dots represent M0 anomaly picks on the North American and European side, crosses denote M0 anomalies on the Iberian side. Note that reconstruction in (b) is clearly incompatible with the seafloor anomaly data in the Atlantic and Bay of Biscay. IB/EUR denotes total reconstruction pole for Iberia with respect to Europe. Amount of rotation is measured in Madrid (circle with bar, ϕ). Note significant difference in total counterclockwise rotation in the two models and difference in implied amount of convergence in the Pyrenean realm.