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The structure of the Temsamane fold-and-thrust stack (eastern Rif, Morocco): Evolution of a transpressional orogenic wedge

Antonio Jabaloy-Sánchez [a,*], Ali Azdimousa [b], Guillermo Booth-Rea [a,c], Lahcen Asebriy [d], Mercedes Vázquez-Vílchez [e,f], José Miguel Martínez-Martínez [a,c], Janet Gabites [g]

[a] Univ. Granada, Geodinámica, Granada, Spain
[b] Laboratoire LGA, Faculté des Sciences, Université Mohammed I, Oujda, Morocco
[c] Instituto Andaluz de Ciencias de la Tierra UGR-CSIC, Avda. de las Palmeras, 18100 Armilla, Granada, Spain
[d] Institut Scientifique, B.P. 703, Université Mohammed V, Agdal-Rabat, Morocco
[e] Andean Geothermal Center of Excellence (CEGA), Universidad de Chile, Santiago, Chile
[f] Department of Geology, Universidad de Chile, Santiago, Chile
[g] Pacific Centre for Isotope and Geochemical Research, Department of Earth and Ocean Sciences, The University of British Columbia, 6339 Stores Road, Vancouver, BC V6T 1Z4, Canada

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ABSTRACT

The structure of the Temsamane fold-and-thrust stack corresponds to four units limited by anastomosing ductile shear zones cutting a trend of south verging recumbent folds. This ductile stack was formed in an inclined left-handed transpressional zone at the North African paleomargin during Chattian to Langhian times producing two main deformational events. The first event (D_p) produced a S_p/L_p planar linear fabric generated in a non-coaxial deformation with a top-to-the-WSW sense of movement and was associated to metamorphic P–T conditions varying from late diagenesis in the southernmost Temsamane outcrops to epizone in the north. According to the $^{40}Ar/^{39}Ar$ ages, this deformation occurred at Chattian–Aquitanian times. The second deformational event (D_c event) generated ENE–WSW trending folds with SSE vergence and a set of anastomosing shear zones with S_m/L_m planar linear fabric. The latter units were generated at around 15 Ma (Langhian), and indicate a strong localization of the simple shear component of the transpression. Moreover, this orientation is compatible with the kinematics of the Temsamane detachment, which can explain most of the uplift of the Temsamane rocks from the middle to the uppermost crust. The described evolution indicates that collision between the western Mediterranean terranes and the North African paleomargin and the formation of the Rifean orogenic wedge occurred at Chattian to Langhian times.

1. Introduction

The original concept of transpression/transtension was defined by Harland (1971) and Sanderson and Marchini (1984) as strike–slip deformations that deviate from simple shear because of a shortening (or extension) component orthogonal to the deformation zone. As most plate tectonic kinematics are oblique to plate boundaries, transpression/transtension is one of the most common deformational regimes in the lithosphere (Dewey et al., 1998). Different theoretical models have been proposed to determine a mathematical description of transpressional zones and the evolution of their fabrics and structures (e.g., Dewey et al., 1998; Jiang et al., 2001; Czeck and Hudleston, 2003; Fernández and Díaz-Azpiroz, 2009; among others). The primary difficulty is the complex and poorly understood deformation patterns that were generated in many transpression zones, where field studies show that structures differing significantly in orientation may form simultaneously (e.g., Dewey et al., 1998).

The theoretical models pose several questions related with the deformation of the transpressional zones. One of these questions is whether the strain is non-partitioned or partitioned in the deformation zone (Dewey et al., 1998). Most of the models on transpressional deformation zones assume that the strain must be partitioned into the boundary-normal strain and the boundary-parallel strain components (e.g., Dewey et al., 1998; Jiang et al., 2001; Molnar, 1992; Platt, 1993). Moreover, most of the models assume a deformational zone with vertical geometry, whereas dipping deformational zones or the so-called inclined transpressional zones are scarcely discussed (Dutton, 1997; Jones et al., 2004).

Furthermore, most of the transpressional zones suggest localization of the non-coaxial component of the transpression (simple shear),

* Corresponding author. Tel.: +34 958 243365; fax: 34 958 248527.
E-mail address: jabaloy@ugr.es (A. Jabaloy-Sánchez).

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whereas the coaxial component remains non-localized in the entire deformational zone (Jiang et al., 2001; Lin et al., 1998).

Another major question is the presence of differential vertical movements within the parts of the transpressional wedge, producing the exhumation of rocks from deep crustal levels (e.g., Spotila et al., 2007).

The eastern Rif forms the southern branch of the Betic–Rif orogen (Fig. 1), and is considered an orogenic belt formed in a left-lateral transpressive regime (e.g., Platt et al., 2003, 2013; Booth-Rea et al., 2005; Balanyá et al., 2007). It is essentially composed of Mesozoic to Cenozoic rocks affected by ductile penetrative deformations and low- and very low-grade metamorphism that decreases westwards (Frizon de Lamotte, 1985, 1987; Negro et al., 2007; Suter, 1980), suggesting that most eastern Rif rocks were buried at depth during the Alpine orogeny and later exhumed to the surface. The mode and age of deformation and exhumation of these metamorphic rocks in the inclined transpressional zone is not well known; only recently Booth-Rea et al. (2012) have proposed a mechanism for the exhumation of part of the eastern Rif's lowermost units (Temsamane fold-and-thrust stack) by means of a brittle–ductile extensional detachment.

The main aim of this work is to analyze the structure of the Temsamane fold-and-thrust stack in the eastern Rif in order to establish its tectono-metamorphic evolution. To do so, we present new structural, metamorphic and radiometric ages that constrain the evolution and exhumation mechanisms for the regional metamorphic rocks. The understanding of how and when these metamorphic rocks were deformed and exhumed constitutes a key to the evolution of the Betic–Rif orogen and the western Mediterranean area as well as for other transpressive orogenic belts. The main reason is that it can improve our knowledge of the vertical movements of rocks within a transpressional deformation zone and its relationship with both the strain partitioning and localization of the strain components in an inclined transpressional zone.

2. Geological setting

The Rif is an Alpine mountain belt fringing northern Morocco that continues towards the Betic belt in southern Spain to form the Betic–Rif orogen (e.g., Booth-Rea et al., 2005; Chalouan et al., 2008; Platt et al., 2013 and references therein). This orogen resulted from the westward movement of the Alborán domain (Balanyá and García-Dueñas, 1987), at the same time as the African and Eurasian plates converged (e.g., Chalouan and Michard, 2004; Jolivet et al., 2003) (Fig. 1). During the movement of the Alborán domain, both the South Iberian and the North African paleomargins were subducted, producing HP metamorphism in the rocks of the South Iberian margin, namely the Nevado–Filábride complex in the Betic orogen (Behr and Platt, 2012; Gómez-Pugnaire et al., 2012), and IP–LT metamorphism in the rocks of the north African paleomargin (Negro et al., 2007, 2008).

The Rif is composed of three main structural domains from the south towards the Mediterranean coast: the External Rif, the Maghrebian Flyschs nappe complex, and the Internal Rif or Alborán domain (Fig. 1). The External Rif is mainly formed of Mesozoic to Cenozoic sediments and metasediments, and is interpreted as the North African passive margin of the Tethys Ocean, although recently, part of the External Rif (Mesorif) has been interpreted as rest of ophiolitic units that may represent allochthonous remnants of the Tethyan oceanic floor (Benzaggagh et al., 2014). Their rocks are overthrust by the Maghrebian Flyschs units. The rocks of the Maghrebian Flyschs nappe complex are mainly turbidites and also include basalts with MORB affinities interpreted as rocks from the main suture of the Tethys Ocean (Duran-Delga et al., 2000). They are overthrust by the Internal Rif or Alborán domain. The deformations affecting the North African paleomargin ranged mainly from the Oligocene to the Miocene (Chalouan and Michard, 2004; Chalouan et al., 2008).

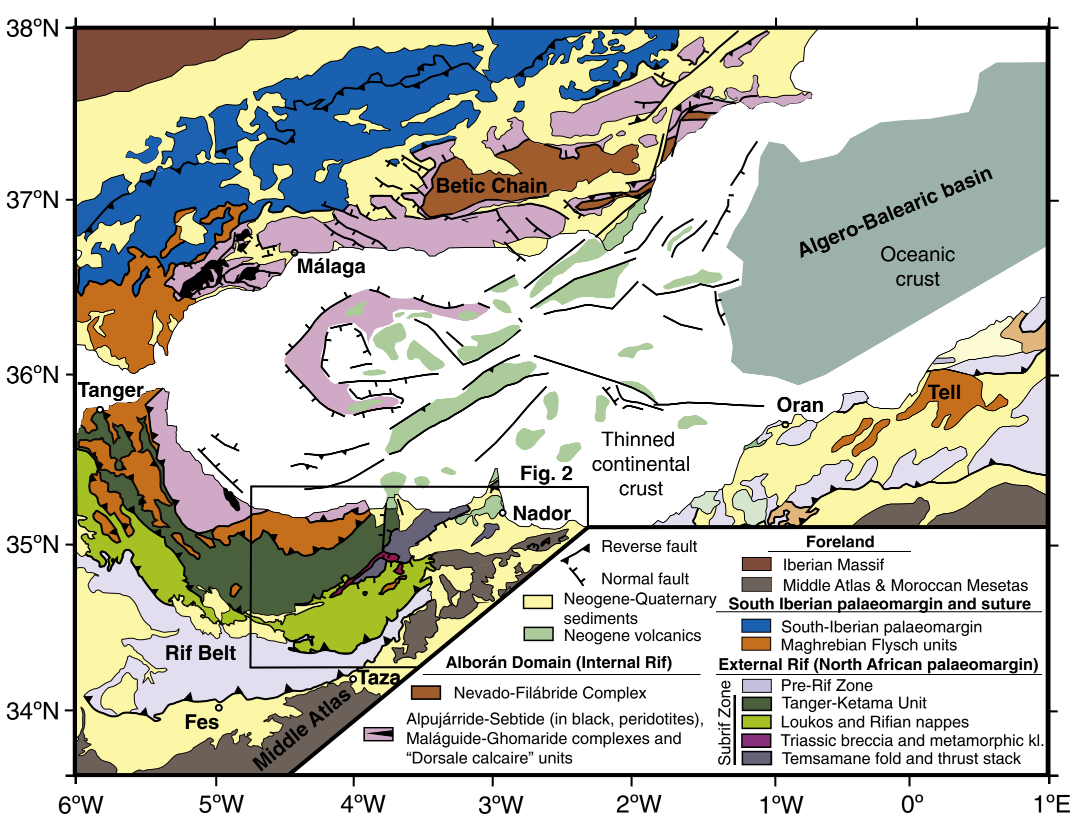

Fig. 1. Geological map of the main geological domains in the Betic–Rif orogenic system surrounding the Alborán Sea. The location of the study area represented in Fig. 2 is marked with the black rectangle.