C-2 ALPINE TECTONIC EVOLUTION OF THE W MEDITERRANEAN

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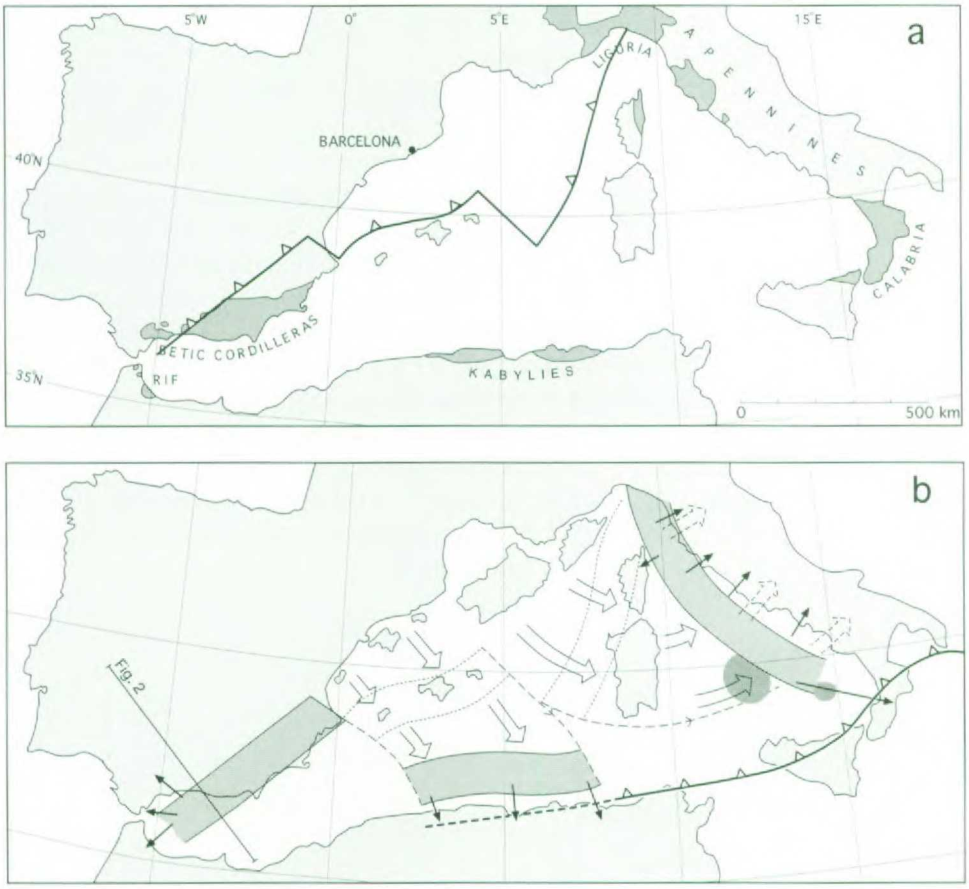

Fig. 1. Alpine kinematic evolution of the W Mediterranean, after Zeck (1999). (**a**) Final stage of subduction with Iberian plate colliding with continental Betic-Ligurian lithosphere after Mesozoic oceanic Tethyan lithosphere has been subducted W-wards under E-ward drifting Iberia (cf. Fig. 2). The subduction system comprises three segments of active subduction separated by two transform fault zones. Core complexes (after Coward & Dietrich, 1989) in dark shading. (**b**) Miocene stage of extensional regimes with slab roll-back and local slab detachment involving opening of the Gulf of Valencia, the Provençal-Algerian basin and Tyrrhenian basin, but prior to the latest stage extension in the southern Tyrrhenian Sea basin (Vavilov and Marsili oceanic basins in dark shading) which translated the slab further towards the southeast (hatched double arrows) and assisted in the final emplacement of the Calabria core complex, overriding the E-W trending subduction system (hinge line in bold) accomodating N-S Europe-Africa convergence.

SCATTERED ALPINE OROGENIC BELT IN THE W MEDITERRANEAN

Tracing on a map (Fig. 1a) the connection between the Alpine orogenic core complexes in the western Mediterranean – from the Rif, the Betic Cordilleras, the Kabylies, Sicily, Calabria, Apennines and Corsica to Liguria – does not readily suggest a geodynamic rationale. Clearly the widely scattered pattern cannot be explained by a N-S African convergence as is often suggested. An alternative model is proposed here based on E-W collision and subsequent fragmentation of the collisional belt by a series of extensional regimes. The model has some aspects in common with earlier models suggested by Argand (1922) and Alvarez (1976).

IBERIA – BETIC-LIGURIA E-W COLLISION *versus* EUROPE – AFRICA N-S COLLISION

The Betic-Rif belt may serve to illustrate the collisional stage. Most current tectonic models rely on N-S convergence of African and European plates with the formation of a c. 250 km thick E-W trending collisional prism and lithospheric root. A central element in many of these models is the late stage convectional removal of the thickened lithospheric root, and this was proposed to have resulted in regional topographic uplift and late stage extensional tectonics and collapse of the Alborán area (e.g., Platt & Vissers, 1989). However, seismicity and seismic tomography studies in the region do not support a E-W oriented subduction zone (e.g., Grimison & Chen, 1986; Blanco & Spakman, 1993; Zeck, 1996, 1997). Neither the small magnitude of the N-S Africa-Iberia convergence (150 - 200 km; Dewey et al., 1989; Srivastava et al, 1990) supports these models.

Based on the detailed North Atlantic spreading chronology obtained by Srivastava et al. (1990), Zeck (1996) suggested a minimum age of c. 55 Ma for the start of subduction activity in the Betic-Rif system and c. 25 Ma for slab break-off. These age estimates build on the assumptions that North Atlantic sea floor spreading and subduction east of Iberia acted in concert and that the rate of slab sinking is comparable to the rate of subduction and sea floor spreading. The position of the nose of the vertical slab at c. 600 km below the general base of the lithosphere (Fig. 2) then translates into an approximate start of subduction at c. 55 Ma, that is the age of chron 22-23, running at c. 600 km east of the Mid-Atlantic ridge (cf. Srivastava et al., 1990, fig.1). Similarly, the age of slab break-off (Fig. 2) would correspond approximately to the age of chron 6c-7 (c. 25 Ma), running at c. 200 km east of the Mid-Atlantic ridge. The age estimate for the start of subduction thus obtained should be regarded as a minimum value as formation of syn-collisional nappe complexes will have absorbed part of the E-ward drift, while another part may have been accommodated further east in the Alpine tectonic system. Initially subduction involved oceanic lithosphere, whereas formation of collisional nappe complexes took place later. Direct age information on timing of Alpine collisional tectono-metamorphism in the Betic-Rif orogen is sparse and not very well defined, see Zeck (1999) for a compilation.

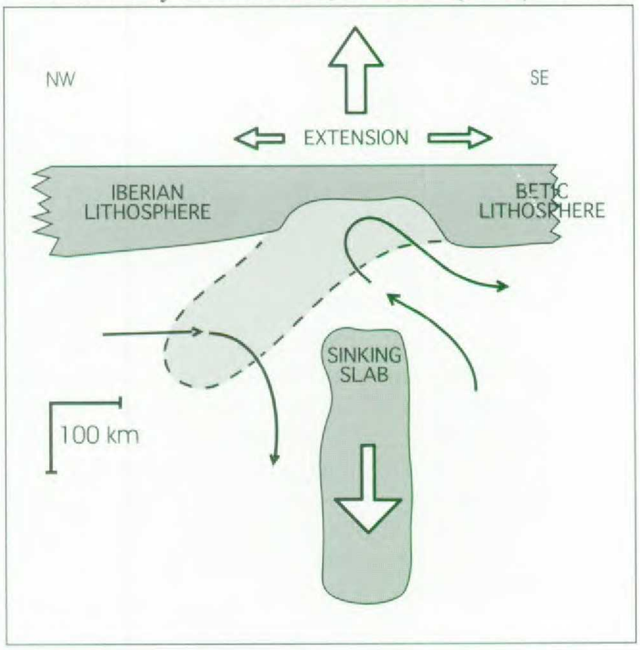

Fig. 2. Cross-section outlining the sinking slab model suggested for the Betic-Rif (Zeck, 1996, 1997, 1999). The section runs approximately through the island of Alborán which is located over the SE boundary of the slab (cf. Fig. 1). Hatched line outlines the subducted Tethyan oceanic lithospheric slab at the final, collisional, stage of subduction, before slab break-off.

POST-COLLISIONAL SLAB ROLL-BACK AND SLAB DETACHMENT

The SW-NE striking Betic-Ligurian subduction zone system (Fig. 1a) had a segmented character: three segments with subduction activity being separated by two transform fault zones. Break up of the collisional belt, formed after Tethyan oceanic lithosphere had been subducted, took place during a series of Miocene extensional regimes patterned upon its segmented structure. In the southern, Betic, segment the Betic-Rif collisional wedge was not subsequently affected by a slab roll-back development. The subducted, and detached, Betic-Rif lithospheric slab is at present located under the Betic-Rif orogen (Figs. 1a, 2). The intermediate, Balearic-Kabylian, segment underwent slab roll-back after collision which indicates that the

Kabylian collision wedge was a small continental fragment located between Tethyan oceanic lithosphere which was subducted W-ward before collision and Tethyan oceanic lithosphere which was peeled back SE-ward after collision. The northern, Corsica-Sardinia, segment likewise underwent considerable slab roll-back after subduction, concomitant with back-arc type extension both in the Provençal-Algerian basin west of Sardinia and between eastern Sardinia and the Calabrian collisional wedge which was located close to the slab trench (Figs. 1b, 3). This indicates that also the Calabrian collisional prism was a small continental fragment within the Tethyan realm. It thus seems that the rather irregular pattern of extensional basins and roll-back trenches which characterizes the western Mediterranean reflects the distribution pattern of continental and oceanic lithosphere in the Tethyan realm prior to Alpine tectogenesis. The ultimate SE-wards emplacement of the Calabrian core complex took place under the influence of the latest stage, c. 7-0 Ma extension involving generation of oceanic crust in Vavilov and Marsili basins.

PRESENT DAY EUROPE-AFRICA N-S CONVERGENCE

The tectonic evolution model presented here implies that N-S convergence played a minor role in western Mediterranean tectonics, whereas in the eastern Mediterranean its influence was much

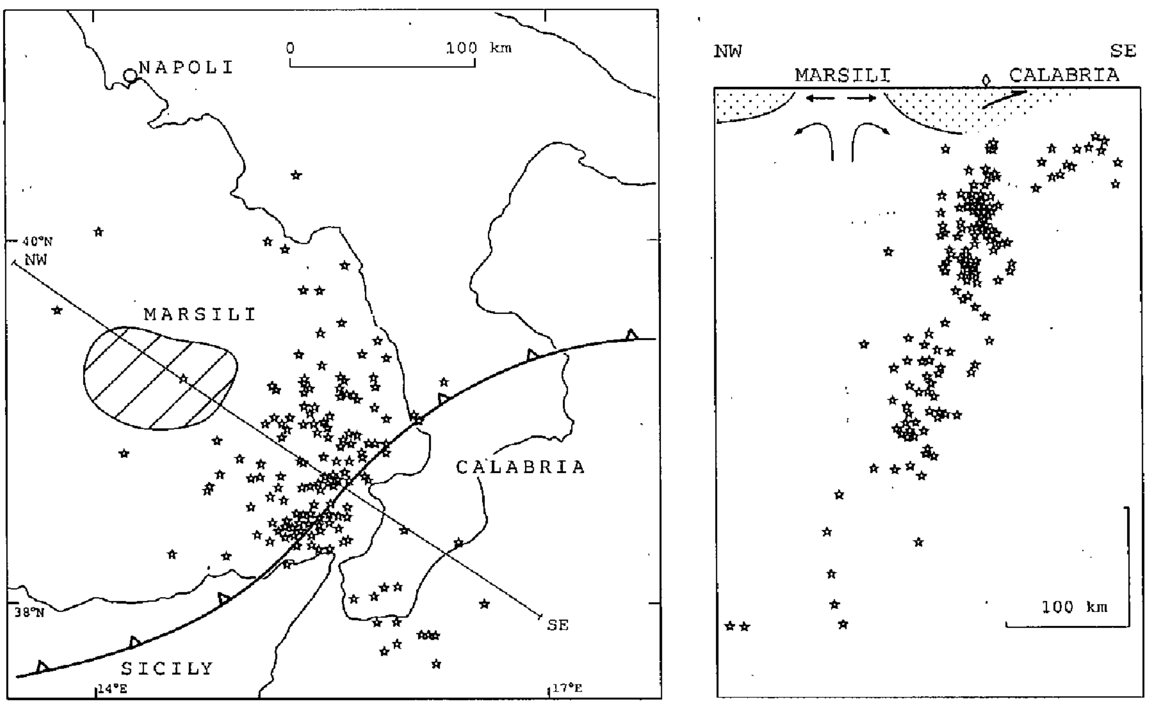

Fig. 3. **(Left)** Sicily-Calabria area with seismic epicentres of events >50km depth during the period 1988-1993; data from Selvaggi and Chiarabba (1995). Marsili oceanic crust floored basin in striped signature. In bold: hinge line of subduction system which steeply N-dipping Tethyan oceanic lithosphere is overridden by European (crustal) lithosphere (cf. Fig. 1b).

(Right) Cross section (location in figure on the left) showing seismicity outlining steeply N-dipping subducted Tethyan oceanic lithospheric slab; diamond on top frame indicates intersection point with the subduction zone hinge line indicated in figure on the left.

more important due to the sinistral hinged movement of the African plate with respect to Eurasia (Dewey et al, 1989; Srivastava et al., 1990). This led to development of the well defined E-W trending subduction zone system dipping N-ward under Crete. It is suggested here that this subduction zone continues W-ward over Calabria and Sicily (Fig. 3) and further W-ward north of the African plate (Fig. 1b), loosing importance on the way.

The tectonic complexities in the Sicily-Calabria region (e.g., Dewey et al., 1989) may be explained by its location in a zone where two different tectonic regimes meet, one controlled by the E-W convergent Betic-Ligurian subduction zone system and its off-spin of E(-SE)-vergent allochthons following slab roll-back translations, the other controlled by N-ward subduction of Tethyan oceanic lithosphere (Fig. 3) under the influence of N-ward drift of Africa with respect to Europe.

CONCLUSIONS

The alpine tectonic belt in the W Mediterranean shows a widely scattered pattern which reflects a complicated history involving subduction, slab roll-back and slab break-off. Integrating a wide range of multidisciplinary data, i.a., seismic tomography features, regional tectonic transport directions and ages of subduction/collision, lithospheric extension and slab detachment, suggests a new model for the development of the Alpine belt in the western Mediterranean. The model implies that the backbone of the Alpine orogeny was formed by a composite SW-NE striking subduction system that had its main activity perhaps during the period 70-30 Ma. The system which consumed Mesozoic Tethyan lithosphere was W-ward dipping under the leading edge of Iberia which was drifting E-ward with respect to North America under the influence of the opening of the North Atlantic. Allowing for a series of late stage extensional regimes, with local formation of Neogene oceanic lithosphere, in the Valencia Gulf, Provençal-Algerian basin and southern Tyrrhenian basin, and inherent slab roll-back, the original collision belt may be reconstructed comprising all present Alpine metamorphic core complexes in the western Mediterranean – Betic-Rif, Kabylies and the Sicily-Apennines(-Corsica) belt. It follows that in the western Mediterranean N-ward drift of Africa against Iberia/Europe, though influential, e.g., in creating the E-W grain of the Betic Cordilleras, has not been the controlling factor. In contrast, in the eastern Mediterranean the influence of N-S convergence has been much more pronounced due to the hinged sinistral movement of the African plate. A major part of the Europe-Africa N-S convergence was accommodated in a coherent N-dipping subduction zone running from North Africa over Sicily-Calabria to Crete, gaining importance on the way.

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