Comment on "The ultimate arc: Differential displacements, oroclinal bending, and vertical axis rotation in the External Betic-Rif arc" by J.P. Platt et al.

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[1] *Platt et al.* [2003a] have made a major contribution to our knowledge of the Gibraltar arc by documenting the kinematics of the Betic-Rif External zones through structural and palaeomagnetic measurements. They suggest that the "External Betic-Rif arc" is a thin-skinned fold-and-thrust belt formed in Miocene time as a result of two causes, i.e., first, the westward component of motion of the "indenting Alboran Domain" (Betic-Rif Internal zones) relative to the convergent Iberian and African plates; and second, the extensional collapse of the Alboran Domain.

[2] The concept of an "indenting Alboran Domain" goes back to the work of *Andrieux et al.* [1971], who referred to an "Alboran microplate." We argue hereafter that the "Alboran Domain" did not act as an indenter, and that both its collapse and the external Betic and Rif fold belts are consequences of a slab retreat process. We also emphasize that defining the Betic and Rif external fold-and-thrust belts as a single, thin-skinned arc is misleading.

[3] The crucial role of the late orogenic collapse in the building of the Betic-Rif chain goes back to the work of *Platt and Vissers* [1989], who assumed that it was an intracontinental collisional orogen, formed at the expense of the neighboring Iberian and African margins, without any oceanic domain nor exotic terrane in between. However, relics of lost oceans do occur (1) along the African margin, i.e., the Beni Malek serpentinites and basalts at the very edge of the margin [*Michard et al.*, 1992] and the spilites and radiolarites at the bottom of the exotic Flyschs [*Durand-Delga et al.*, 2000], which altogether document a former Maghrebian ocean, and (2) on top of the Nevado-Filabrides units of central eastern Betics, i.e., the metaserpentinites and metabasalts of the Mulhacen complex, which document a former Betic ocean [*Puga et al.*, 1999, 2002a, 2002b]. The occurrence of former oceanic domains makes necessary to consider subduction processes there. Some authors even assume that two subduction zones operated, first the SE dipping Alpine-Betic subduction, then the NW dipping Apenninic-Maghrebian subduction [*Rehault et al.*, 1984; *Torres-Roldan et al.*, 1986; *Andrieux et al.*, 1989; *Guerrera et al.*, 1993; *Doglioni et al.*, 1998, 1999; *Frizon de Lamotte et al.*, 2000; *Chalouan et al.*, 2001; *Michard et al.*, 2002; *Chalouan and Michard*, 2004]. Consistently, east dipping active subduction beneath the Gibraltar arc is currently evidenced [*Morales et al.*, 1999; *Gutscher et al.*, 2002].

[4] *Platt et al.* [2003a] accept the concept of an easterly, allochthonous "Alboran Domain." In fact, the latter includes two different tectonic systems, the Nevado-Filabrides (NF) at the bottom, and the "Alboran Terrane" on top, which in turn consists of the metamorphic Alpujarrides-Sebtides (AS) overlain by the Malaguide-Ghomarides and Dorsale Calcaire units [*Chalouan et al.*, 2001; *Michard et al.*, 2002, and references therein]. The NF consists of the HT-LP Veleta schists overlain by the HP-LT Mulhacen Complex, which has the characters of a subduction tectonic complex [*Puga et al.*, 1999, 2002a, 2002b]. Only the Alboran Terrane does represent an exotic domain of easterly origin [*Bouillin et al.*, 1986; *Michard et al.*, 1991, 2002]. As the Alboran Terrane formed at the onset of Neogene times an orogenic prism made of young, ductile metamorphic units, it can hardly be regarded as an "indenter," which would be the initial cause of the "External Arc" building. We rather suggest considering that the Alboran Terrane operated as a backstop related to the subduction of the Maghrebian Tethys (see section 6).

[5] *Platt et al.* [2003a] argue that "the present dramatic geometry of the arc is a result of extensional collapse of the Alboran Domain during the Miocene." They agree that the subduction rollback hypothesis [*Frizon de Lamotte et al.*, 1991; *Lonergan and White*, 1997] could be "reasonably" proposed, but prefer the collapse mechanism that they also consider as the cause of the opening of the Algerian basin

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Tyrrhenian and Ligurian seas. In another, almost coeval paper, *Platt et al.* [2003b] present the convective removal of subcontinental lithosphere as the only mechanism which may completely explain the late orogenic extension in the Alboran area. Likewise, *Platt et al.* [2003c] suggest a gravitational emplacement of the Ronda peridotites on top of a deeper Alpujarride crustal unit, while the compressional emplacement of these mantle slices within the Alpujarride nappe stack has been demonstrated by *Balanyá et al.* [1997, 1998].

[6] At the scale of the whole western Mediterranean, after the pioneering work of *Rehault et al.* [1984], the occurrence of a north dipping subduction zone from Oligocene up to Present was demonstrated repeatedly based on structural, sedimentary, magmatic, paleomagnetic, and/or tomographic arguments [*Frizon de Lamotte et al.*, 1991; *Royden*, 1993; *Lonergan and White*, 1997; *Faccenna et al.*, 1997; *Gueguen et al.*, 1997; *Boccaletti et al.*, 1997; *van der Meulen et al.*, 1999; *Maury et al.*, 2000; *Frizon de Lamotte et al.*, 2000; *Crespo-Blanc and Campos*, 2001; *Michard et al.*, 2002; *Jolivet et al.*, 2003; *Faccenna et al.*, 2004]. *Doglioni et al.* [1998, 1999] and *Michard et al.* [2002] emphasized the continuity of this subduction zone with the backthrust zone of Western Alps. HP-LT metamorphism constitutes the petrological record of this subduction zone in Tuscany and Calabria [*Brunet et al.*, 2000; *Rossetti et al.*, 2001], and possibly in the Rif and Betics [*Chalouan and Michard*, 2004].

[7] Iberia and Africa are two distinct plates. The southern Iberian margin and the North-African margin show contrasting sedimentary histories. Then the Betic-Rif external zones do not really form an "arc." The arcuated internal zones have two distinct foreland belts, separated by a major plate boundary, i.e., the western prolongation of the Azores-Gibraltar transform fault.

[8] The external Rif cannot be defined as a thin-skinnned fold-and-thrust belt [*Platt et al.*, 2003a]. Crustal rocks crop out in the eastern external Rif, i.e., the Beni Malek serpentinites [*Michard et al.*, 1992; *Elazzab et al.*, 1997] and the Paleozoic crystalline rocks of the Senhadja unit [*Andrieux*, 1971], showing that the basement is involved in the compressional structures there. Only the more external part of the belt (Prerif) is a thin-skinned fold-and-thrust belt [*Zizi*, 1996, 2002]. *Frizon de Lamotte et al.* [1991], *Favre* [1995], and *Chalouan et al.* [2001] presented cross sections of the External Rif consistent with these data. Accordingly, the shortening estimates proposed by *Platt et al.* [2003a] are exaggerated. In addition, gravity modeling by *Favre* [1995] suggests that the African Moho deepens down to ~35 km depth beneath the northernmost external units (Intrarif), and then that the top of the thinned margin crust deepens at ~20 km depth there, more than twice the depth indicated by *Platt et al.* [2003a] in their Figure 14.

[9] The presentation of the External Rif as the result of "the extensional collapse of the Alboran domain during the Miocene" is controversial. The existence of a pre-late Oligocene (likely late Eocene) compressive event in the Intra- and Mesorif has been emphasized by *Andrieux* [1971], *Monié et al.* [1984], *Morley* [1992], *Favre* [1995], and *Chalouan et al.* [2001]. This early inversion occurring along the foot of the African margin cannot be explained by the alleged collapse. More generally, the overall Miocene deformation suggests an accretionary prism related to the westward retreat of the Maghrebian slab (see *Flinch* [1996] or *Zizi* [2002]).

[10] As for the Ronda section of the external Betic domain presented by *Platt et al.* [2003a] in their Figure 11, it does not fit the actual structure of the area as (1) the allochthonous Flysch units are not overlain by the Internal Subbetic units (except quite locally, because of their common, late deformation), but are thrust over the latter [*Crespo-Blanc and Campos*, 2001; *Luján et al.*, 2003, and references therein]; (2) seismic lines at the southern boundary of the Guadalquivir basin show that the top of the Hercynian basement deepens much more quickly to the SE beneath the Prebetic-Subbetic domain, up to depths in excess of 10 km below the Internal Zones [*Berástegui et al.*, 1998, and references therein].

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