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Short communication

Discussion: The Betic Cordilleras (SE Spain). Anatomy of a dualistic collision-type orogenic belt, by C. Biermann, *Geologie en Mijnbouw 74: 167–182, 1995*

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In a recent paper, Biermann (1995) presents an overview of the orogenic evolution of the Betic Cordillera. Based upon a concise outline of the geological dataset on the Cretaceous and Tertiary history of the region, Biermann discusses different and currently contending explanations for the Oligo-Miocene extension in the Betic-Alboran system, including that of 'extensional collapse of previously thickened continental crust (Dewey 1988; Platt & Vissers 1989)'. In his discussion of this hypothesis, Biermann writes: 'The model seems attractive but does not explain the driving process of lithospheric root detachment. One possibility is that removal of the lithospheric root was caused by detachment of part of the subducted lithosphere slab underneath the former collision zone (. . .). A problem that remains however, is that collapse of the orogenic wedge should end when the extended domain has sunk topographically lower than the zone of thrusting. Subsidence in the Alboran Basin started in the Late Aquitanian–Early Burdigalian (. . .), indicating that thrusting in the Betic Cordilleras was contemporaneous with marine sedimentation in the Alboran Basin' (Biermann 1995: p. 173).

There are several elements in the above sections of Biermann's paper that urge me to elucidate some of the critical details of the working hypothesis as proposed by Platt & Vissers (1989). These authors suggested that a Paleogene collisional ridge in the Alboran realm would have been underlain by a thick root of cold lithospheric mantle. Following Houseman et al. (1981) and England & Houseman (1988) they suggested (Platt & Vissers 1989: p. 543) that such a root was gravitationally unstable, and that it became detached and descended into the deeper mantle. With reference to England & Houseman (1988) it was argued that detachment of the lithospheric root caused a significant increase in the surface elevation and gravitational potential energy of the collisional ridge or plateau, such that the vertical stresses generated by the region of elevated crust exceeded the horizontal stresses associated with plate convergence, and the region started to extend. Finally, it was explicitly suggested that the lithospheric root would have been removed by convection and replaced by asthenospheric mantle.

Turning to the above quoted sections of Biermann's (1995) paper, it is first underlined that the working hypothesis of Platt & Vissers (1989) involved the *convective removal* of a *gravitationally unstable* lithospheric root, not the detachment of a gravitationally unstable subducting lithosphere slab. In both cases, however, it is clear that the detachment process is driven by gravity. More importantly though, it is emphasized that the working hypothesis of Platt & Vissers (1989) concerned the extensional collapse of thickened continental *lithosphere*, not crust. The difference between these is crucial to Biermann's argument that extension should end as soon as the extended domain has sunk topographically lower than the adjacent zone of thrusting. As shown below, this notion, also put forward by Dewey (1988), is demonstrably incorrect for the case of late-orogenic extension caused by a detachment process in the upper mantle. This can best be illustrated on the basis of a simple numerical experiment by Platt & England (1994) investigating the effect on surface elevation and change in potential energy of a standard lithosphere with a crust of given thickness, subject to thickening followed by detachment of the lower part of the thickened lithospheric mantle triggering extensional collapse (Figure 1). Aside the initial crustal thickness, the numerical results of such calculations clearly depend on parameter values chosen for temperature-dependent densities of crustal and

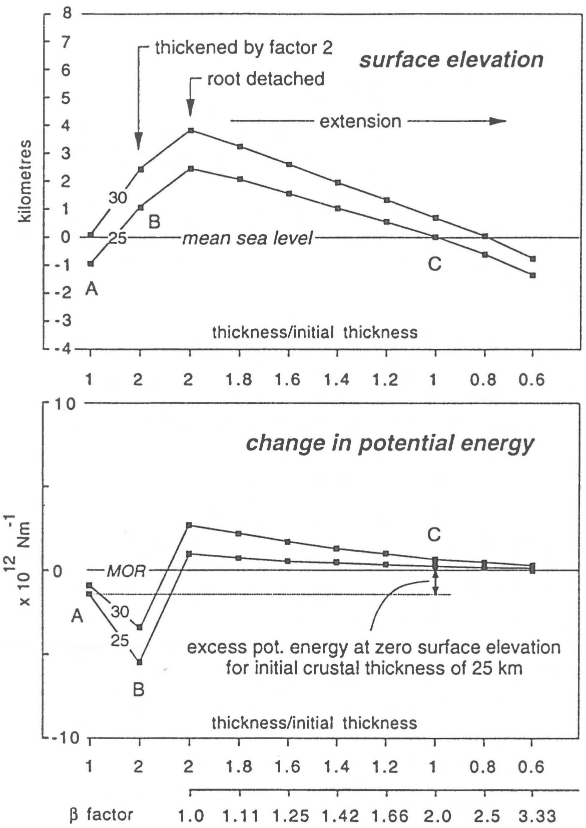

Figure 1. Changes in surface elevation and gravitational potential energy as a result of lithosphere thickening, followed by convective removal and subsequent late-orogenic extension, for initial crustal thicknesses of 25 and 30 km and an initial lithosphere thickness of 125 km, modified after Platt & England (1994). Convective removal is supposed to reduce the thickness of the lithosphere to its initial thickness (125 km). For further discussion see text.

upper mantle rocks, the thickness of the lithosphere and the amount of lithosphere removed, but for reasonable ranges of such parameter values the results are essentially the same. The principal results of such calculations, illustrated in Figure 1, are as follows:

1. Thickening of the lithosphere causes an increase in surface elevation but, more importantly, a decrease in gravitational potential energy. This latter effect is due to the negative buoyancy of the thickened and relatively cold, hence dense lithospheric mantle (England & Houseman 1989; Platt & England 1994), and is very clearly illustrated by Molnar et al. (1993) in their analysis of the Tibetan Plateau.
2. The detachment of the lower part of this thickened lithosphere (chosen in Platt & England's calculations such that the remaining column returns to normal lithosphere thickness) causes a further increase of the surface elevation by 1000–1500 m, and a sudden marked increase of the gravitational potential energy which, in all cases, becomes higher than that of a reference mid-oceanic ridge and, except for high initial crustal thicknesses, higher than that of the undeformed column.
3. Subsequent extension lowers the surface elevation, but the potential energy of the column deprived of its thickened root decreases only slightly towards the MOR reference value.

A major implication pertinent to this discussion is that the extending lithospheric column, having lost its lithospheric root, has at all stages of extension a higher gravitational potential energy than both the undeformed column (labelled A in Figure 1) and the thickened column (labelled B), *even when the surface elevation has become zero or negative* (labelled C for an initial crustal thickness of 25 km). It follows that such a column with zero or negative surface elevation can exert work on an adjacent foreland (undeformed column) and certainly on possible remnants of thickened lithosphere adjacent to the domain where detachment occurred and which may have a surface elevation of over 1000 m above sealevel. This conclusion is fully consistent with and supported by the observation that mid-ocean ridges, even though they have a lower surface elevation, demonstrably exert an outward stress on the continents as evidenced both by the fact that most continents are in a state of horizontal deviatoric compression and that oceans such as the Atlantic continue to spread.

It may be argued that the calculations illustrated in Figure 1 do not incorporate the gradual cooling of the asthenosphere once detachment has occurred; however, the pertinent geological and geophysical data clearly show that extension in the Betic-Alboran domain proceeded on a time scale almost an order of magnitude faster than thermal relaxation of the system. I therefore conclude that Biermann's objections quoted above do not suffice to reject the working hypothesis proposed by Platt & Vissers (1989). Instead, the mere fact that in the context of overall convergence extension proceeded even when the Alboran column came close to sealevel demonstrates that a change must have occurred in the boundary conditions at the base of the system, in other words, a change in the upper mantle structure of the type envisaged.

It is surprising that Biermann (1995) has omitted to quote some of the recent geophysical work pertinent to the problem of the Neogene large-scale tectonics in the Alboran region. A seismological study by Blanco & Spakman (1993) concerned with the P-wave velocity structure of the West Mediterranean mantle suggests the presence of a positive velocity anomaly between 200 and 700 km depth below the Betic-Alboran region. The shape and amplitude of this anomaly is thought to resemble the image of a subducted lithosphere slab. This observational result, entirely independent of any geological data, lends distinct support to the hypothesis that some form of detachment of cold lithosphere occurred in the region. Platt & Vissers (1989) suggested convective removal of a gravitationally unstable lithospheric root, whilst Blanco & Spakmann (1993) suggested the detachment of a lithosphere slab. As noted already, Biermann (1995) somewhat confuses these two interpretations in his discussion of the Platt & Vissers (1989) hypothesis by referring to his Figure 4b which clearly shows the detachment of a subducting slab. A comparison of the two interpretations lies beyond the scope of this discussion, but for the case of the Betic-Alboran system for which all reconstructions suggest an at best small oceanic domain at the onset of convergence, the difference may be effectively small (e.g. Van der Wal & Vissers 1993).

On page 175, Biermann concludes to suggest '. . . that extension in the Betic Cordilleras is neither fundamentally and genetically linked nor restricted to the specific collision zone in the Betic-Alboran domain, but is related to a much wider regional Cenozoic extensional system in western Europe (Ziegler 1988) that can be followed from the Rhone Graben southwards into the extensional basins in the western Mediterranean (. . .)'. I feel that Biermann raises confusion here between kinematic and dynamic arguments. Obviously, extension in the Betic-Alboran region is *kinematically* linked to the observed extension in the adjacent domains; however, this does not answer the question what caused the extension in these domains, nor does it explain the late-orogenic extension seen in the Betic-Alboran realm in terms of its dynamics or the dynamics at a larger scale. I must conclude, that insofar as Biermann (1995) does not elucidate the dynamics of extension in the adjacent areas, the kinematics of the western Mediterranean system as a whole does not provide any argument against the hypothesis that extension in the Betic Cordilleras was indeed fundamentally and genetically linked to the development of an intracontinental collision zone.

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