Geophysical Research Abstracts, Vol. 8, 08926, 2006
SRef-ID: 1607-7962/gra/EGU06-A-08926

Geodynamics of the central Moroccan Atlas: a synthesis

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The Atlas system is a natural laboratory for mountain building in continental plate interiors. A key point that has received much attention there is the interaction between crustal thickening and dynamic (mantle) topography in raising the system of mountain belts and high-altitude plains. The High and Middle Atlas derive from Cenozoic inversion of Triassic-Jurassic rift or transtensional troughs (Laville and Pique, 1992, Piqué et al., 2000), where the style of compressional deformation is dominated by a thick-skinned, simple thrust-fold style (Frizon de Lamotte et al., 2000, Teixell et al., 2003, Arboleya et al., 2004). Total orogenic shortening across the High Atlas is modest, ranging from 15 to 24% in the central High Atlas, from where complete balanced sections are available. The patterns of topography appear independent from those of shortening. Crustal thickening alone cannot explain elevation in the High Atlas, where summits exceed 4000 m. The same holds for the Middle Atlas (with altitudes up to 3000 m and shortening $<$15%, Gomez et al., 1988; Arboleya et al., 2004) and for the Anti-Atlas (up to 2000 m, Cenozoic shortening $<$1%). Not surprisingly, seismic refraction investigations failed to detect prominent crustal roots (Wigger et al., 1992), corroborated by gravity modelling, which evidences a generalized state of crustal isostatic uncompensation (Ayarza et al., 2005).

Seismic tomography indicated low velocities in the upper mantle beneath the Atlas system (Seber et al., 1996), and potential-field based lithospheric modelling, carried out by several authors (Zeyen et al., 2005, Teixell et al., 2005, Missenard et al., in press), suggests a prominent lithospheric thinning in the region. Thinning accounts not only for the high topography, but also for the occurrence of alkaline magmatism of cenozoic age, contemporaneous to compression, and for the scarce development of foreland basins. It is attributed to some sort of thermal upwelling, probably with a deep root, but guided in the upper mantle by side effects of the subduction zone of the Gibraltar arc.

Little consensus has been reached in terms of timing of compressional deformation and uplift. Diverse Paleogene to Neogene age spans have been proposed (Gorler et al., 1988, Morel et al., 2000, Frizon de Lamotte et al., 2000, Teson, 2005). The syn-orogenic Ouarzazate basin is the best marker for chronological studies. Recent data suggest that the main thrust deformation in the adjacent, external thrust belt of the High Atlas spans from the late Oligocene-early Miocene to the Pliocene, although probably commenced earlier in the internal parts of the chain. Shortening proceeded at low rates (averaged 3 mm/a in the thrust belt), and it continues with these or lower rates during the Quaternary (pediments and terraces do record mild deformation structures). Flexural modelling demonstrates the competition between thrust and buoyant loads (associated to the lithospheric thining), accounting for the surface elevation and small dimensions of the Ouarzazate basin. On the other hand, preliminary apatite fission track modelling from Jurassic intrusives in the High Atlas (by L. Barbero) yields ages around 80 ma, and suggests continued, possibly post-magmatic cooling up to 60-70 ma, followed by slow cooling up to 20 ma, and then by exhumation to the surface. These results argue against a pre-Cretaceous shortening and erosion in the internal High Atlas.

Issues to be developed in future include the relations between tectonics and surface processes, with emphasis on the relative chronology, feedbacks and the influence of factors as climate or the continental-scale organisation of the drainage network. In terms of deep structure, seismic investigations in the frame of international projects may precise the geometry and causes of lithospheric thinning, and would resolve the deep crustal structure (whether characterized by a mid-crustal detachment connected to the Rif or cut by thrust faults offsetting the Moho), thus documenting how shortening may be accommodated at the depths of intraplate regions.