Major mid-Cretaceous plate reorganization as the trigger of the Andean orogeny

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Introduction

Global plate reorganizations are inescapable events in plate tectonics and must episodically occur. A major mid-Cretaceous plate reorganization marked the final dismembering of Gondwana leading to consolidation of the major present-day continents and oceanic basins. In those times occurred the physical disconnection between South America and Africa as well as the separation of Australia from Antarctica and India from Madagascar. Precise dating of this widespread event is precluded by the lack of seafloor magnetic anomalies from earliest Aptian to the end of Santonian. However extrapolated ages of 95 ± 5 Ma have been assigned to changes in relative plate motion in the South Atlantic Ocean, southwest and southeast Indian Ocean, and Weddell Sea. It is worth noting that the pole of opening for the Central Atlantic does not change for the Aptian-Santonian time interval, suggesting that the mid-Cretaceous plate reorganization mainly affected the former Gondwana region.

The hotspot (HS) fixity axiom was intensively used for many years for tectonics and geodynamics analyses, in particular to determine plate motions with respect to the mantle. However recent findings point to failure of the fixed-HS hypothesis, indicating that the emerging, more realistic scenario where sub-lithospheric melting anomalies move and deform in concert with flow in the surrounding mantle need to be allowed for assaying tectonic and geodynamic models. In this report, a moving-HS model (O’Neill et al., 2005) and paleomagnetism are applied in the analysis of the mid-Cretaceous plate reorganization and its implications for the development of major present-day orogenic systems in general, and the Andean Cordillera in particular.

Cretaceous to Recent evolution of the Andean margin

The Andean magmatic arc that parallels the western margin of South America was almost permanently active since at least the Early Jurassic, pointing out a long-lived subduction history. The coeval evolution of the continental margin may be divided into two periods. During Jurassic to Early Cretaceous times most of the margin was very close to sea level, with backarc shallow seas and extensional basins. In contrast, the Late Cretaceous to Recent interval is characterized by rising of arc massifs and increasing predominance of horizontal shortening, leading to progressive crustal thickening, uplift, development of thrust belts and associated foreland basins.

Figure 1 shows the 120 Ma reconstruction to the moving-HS framework of O’Neill et al. (2005). The synthetic flowlines describing the motion of Africa with respect to the moving-HS suggest that slab pull force in the eastern Tethys subduction zone was an important factor in controlling the motion of that continent during the 120-100 Ma time interval. By those times South America was physically connected to northwest Africa throughout an incipient extensional region in the present day equatorial Atlantic. This way, South America must
have felt both the slab pull force at the Tethys trench and the competing force derived from suction at the Andean subduction zone (Fig. 1). The moving-HS model predicts that about 75% of the 120-100 Ma full spreading in the South Atlantic Ocean is associated with African “absolute” motion, implying eastward motion of the young mid-ocean ridge and, by inference, little (~1.5 cm/yr average in the model) westward motion of South America. This scenario, with South America experiencing little motion with respect to the mantle, allows considering episodes in which oceanward motion of the Andean trench due to slab rollback was faster than westward continental motion, yielding a mechanism to account for the extensional conditions in the western continental margin during the considered time interval. Although no moving-HS reconstructions older than 120 Ma are available, paleomagnetism indicates that South America experienced counterclockwise rotation about a northern pole between 135-125 Ma, suggesting that the continent moved away from its western subduction zone in those times, also consistent with development of extensional conditions at the Andean margin. Hence, paleomagnetic and moving-HS kinematics allow interpreting the development of extensional tectonics in the early Andean margin as the product of episodic divergence between the trench and the continental interior.

Extensional conditions dominated in Peru and central-northern Chile until the Cenomanian (Cobbing et al., 1981; Atherton and Webb, 1989; Mpodozis and Allmendinger, 1993). On the other hand, the first widespread contractional events in the Andean Cycle seem to have occurred in Santonian-Campanian times (Mégard, 1987; Ladino et al., 1999; Tomlinson et al., 2001), suggesting that they began a little later than the final disconnection between Africa and South America in the present day Equatorial Atlantic.

Rifting in the sheared Equatorial Atlantic margins (Fig. 1) started in Aptian times and complete continental disconnection occurred some time during the Cenomanian-Turonian (Basile et al., 1998), although it seems that deepwater connection between central and south Atlantic was not established until Turonian-Coniacian or even Santonian times. The moving-HS model predicts that the westward motion of South America substantially increased (Central Andean average ~4.5 cm/yr between 90-60 Ma) after the final continental disconnection in the Equatorial Atlantic region (inset “a” in Figure 1). This faster westward drift likely led to episodes in which the continent effectively overrode the Andean trench, in agreement with the development of compressive events at its leading edge. This tectonic behavior dominated the Late Cretaceous to Recent evolution of the margin, resulting in an important (predominant?) factor for mountain building in the Andean region.

The moving-HS framework further implies that increasing westward motion of South America was associated with a desacceleration of African drift at about 90 Ma (inset “b” in Figure 1). This African motion slowdown and the continued expansion in the South Atlantic imply that the spreading ridge must have begun to move westward with respect to the mantle, substantially increasing the westward drift of South America. In particular, a velocity increment of ~200 % is predicted between 90 and 80 Ma (inset “a” in Figure 1), a time interval that includes the beginning of contractional deformation in the Andes.

**The Alps and the Himalayas**

The moving-HS model allows envisaging a kinematic scenario where, prior to 90 Ma, northeastern Africa and northern India (or Greater India) constituted the leading edges of these independently drifting landmasses towards the eastern Tethys trench (Fig. 1). The ~90-88 Ma separation of India from Madagascar (Storey et al.,
1995; Torsvik et al., 2000; Raval and Veeraswamy, 2003) and the associated development of the Central Indian oceanic ridge (inset “b” in Figure 1) led to Africa to be almost surrounded by plate-border-parallel spreading ridges. The latter configuration greatly inhibited African motion excepting towards the Mediterranean region, the only remaining “free face” of Africa in the Late Cretaceous. Thus, African motion slowdown at 90 Ma may be related to the establishment of an almost complete girdle of spreading systems around this continent.

Figure 1. Earliest Aptian reconstruction to the moving-HS framework. Oceanic spreading systems (mainly based on identifications of the M0 magnetic anomaly) are shown in red. SB and MB depict Somali and Mozambique basins, respectively. Northern (grey) star is the 120-100 Ma stage pole for Africa-South America relative motion. Southern (black) star is the pole describing the motion of Africa with respect to the moving-HS between 120 and 100 Ma (dashed small circle sectors being the associated synthetic flowlines). Box in the lower part of the draw show the Africa-South America divergence (at the “X” site) decomposed into motion of each one of these continents relative to the moving-HS framework. Inset “a” depicts the westward motion of the Andean region between 120 and 60 Ma. Note acceleration between 90 and 80 Ma, coincident with the beginning of compressive tectonics in the Andes. Inset “b” shows the motion of Africa with respect to the moving-HS between 120 and 60 Ma, note the motion slowdown after 90 Ma. Dashed lines represent the 90-60 Ma synthetic flowlines of the motion of Africa and India with respect to the moving-HS. India and Madagascar are reconstructed at 90 Ma in order to show the paleogeography at the beginning of spreading in the Central Indian Ocean.
In this context, the beginning of Africa-Europe convergence at ~90 Ma triggered the Alpine orogeny, leading to the development of magmatic arcs and the build-up of regional compressional stresses and associated metamorphic events (Ziegler, 1988; Dewey et al., 1989; Okay et al., 2001; Carrapa and Wijbrans, 2003; Ziegler, 2005; Stampfli and Kozur, 2006). On the other hand, the coeval, almost E-W standstill of Africa together with the continued accretion of oceanic lithosphere at its eastern and western margins resulted in fast motion of both India and South America because the South Atlantic and Central Indian spreading ridges also moved apart from the then leisurely drifting Africa. In particular, this kinematics led to fast northward drift of India, accounting for almost the whole oceanic expansion in the early Central Indian ridge, which culminated with its collision with Asia and the associated formation of the Himalayas.

Thus, it is suggested that the above described mid-Cretaceous plate reorganization triggered the Andean and Alpine orogenies as well as the beginning of the plate tectonic conditions that led to the formation of the Himalayas.

References


