

## Slow rates of subduction erosion and coastal underplating along the Andean margin of Chile and Peru: COMMENT and REPLY

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In their article, Clift and Hartley (2007) propose the existence of two alternating modes of subduction erosion for north-central Chile and Peru: one fast, with steady-state retreat from 150 to 20 Ma, and the other slow, with erosion constrained only in the trench domain from 20 Ma onward.

The proposed model is intriguing, as it reveals that subduction erosion is not always by steady-state evolution with mass removal along the entire subduction channel and whole-scale landward retreat. However, we disagree with the timing proposed for these events because we consider that some of the data used in their analysis are incorrect.

Essential in Clift and Hartley's model are paleobathymetric data used to reconstruct vertical motions of the studied Chilean and Peruvian basins. In their study, they indicate that all Neogene sedimentation was limited to the shelf or coastal environments. However, other studies have presented data indicative of bathyal deposition. Achurra (2004) reports that benthic foraminifers indicate lower-middle bathyal (1500–2000 m) deposition in the Caldera basin during the late Miocene and at least part of the Pliocene. His interpretation is supported by the occurrence of manganese nodules formed in a hemipelagic environment (Achurra et al., 2003). Benthic foraminifers also indicate bathyal (500 m) deposition during part of the Pliocene in the Mejillones basin (Ishman et al., 2003). For their analyses of the Peruvian basins, Clift and Hartley extracted data from Dunbar et al. (1990) and Tsuchi (1992). However, none of these authors uses benthic foraminifers in their studies, nor do they make a detailed sedimentological analysis that allows accurate paleobathymetric interpretations. Furthermore, Dunbar et al. (1990) report a temporal shift from nearshore to deeper water organic-rich facies in the Neogene successions of Peru. They do not provide a precise quantification for their "deeper facies," but the inclusion of diatomites and abundant radiolarians strongly suggest it is bathyal.

Clift and Hartley make mention of Miocene shallow-marine successions in central Chile (33°–35°S). However, data derived from benthic foraminifers and supported by sedimentological and ichnological studies indicate lower bathyal deposition (>2000 m) in this area during the late Miocene to early Pliocene, followed by nearshore sedimentation during the late(?) Pliocene and subsequent emersion and uplift of these successions (Encinas et al., 2006; Finger et al., 2007; Encinas et al., 2007). Correlative units in south-central Chile (~37°–43°S) show a similar history (Finger et al., 2007; Encinas et al., 2007) and indicate that basin subsidence and uplift were related to regional tectonics that affected the entire forearc.

Clift and Hartley suggest that the 170 km of eastward arc displacement during the Neogene calculated by Kay et al. (2005) at 33°–35°S is the product of decreasing subduction angle rather than trench retreat. However, the onset of major coastal subsidence for this area during the Neogene is a consistent argument favoring subduction erosion as the cause of arc motion.

One of the most important assumptions in Clift and Hartley's model is that the position of the coast has remained nearly stationary since ca. 20 Ma. One piece of the evidence for this is the occurrence of Upper Cretaceous

to Miocene shallow marine and continental strata exposed along the coast of central Chile (33°–35°S). However, if presently exposed Neogene strata in the Caldera basin and central Chile were deposited at depths of ~2000 m, then the paleocoast must have been located tens of kilometers to the east. In fact, the easternmost occurrence of shallow marine Pliocene successions in central Chile is ~40 km from the present coast (Encinas et al., 2006). Furthermore, marine sequences in central Chile are punctuated by major unconformities between the Upper Cretaceous, Eocene, and Neogene (Gana et al., 1996). These have been recognized in wells drilled on the continental shelf of south-central Chile (~36°–40°S), some located 40 km east of the present coast (Mordojovich, 1981). Whereas the unconformities represent regressive intervals of uplift, nondeposition, and erosion, the position of the paleocoastline must have oscillated widely.

In conclusion, we share Clift and Hartley's point of view that there are alternating periods of fast and slow tectonic erosion, but we do not agree that a slow pace characterizes the last 20 m.y. Major subsidence of the coastal area between ~20–11 to 4–2 Ma (ages may vary depending on the area) indicate subduction erosion with mass removal along the entire subduction channel, from trench to coast, with eastward displacement of the coastline and a rapid erosion mode. In our opinion, the slow erosion mode did not commence until sometime within the last ~4–2 m.y.

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We thank Encinas and Finger (2007) for their comments on our paper (Clift and Hartley, 2007), as they add detail to the model we presented, while leaving intact the essential idea of Neogene tectonic erosion along the Andean margin being followed by accretion and underplating since 2 Ma. Our analysis and erosion rate estimates hinge on paleobathymetry data that were compiled from a series of published studies and enhanced by field observations by Hartley. In essence, the Comment suggests that some of the Upper Miocene and Pliocene sections were actually deposited in much deeper water than we calculated, and consequently, that subsidence rates, and thus rates of tectonic erosion, would have been much higher at that time. However, we did not incorporate some of the data referred to because they are not peer reviewed or published in the open literature (Achurra, 2004; Achurra et al., 2003), or they are not still in press. In any case, Achurra et al. (2003) stated that the sediments in the Caldera basin were hemipelagic, but this does not imply a specific water depth. Dark shales and diatomites are often deposited in deep water, but are not restricted to such zones, and their accumulation is also dependent on paleoceanographic conditions. More robust benthic foraminifer studies (Resig, 1990) from Lima Basin, further northwest, indicate that water depths on the Peruvian shelf have been approximately constant since the Eocene, interrupted by periods of emergence, but not bathyal conditions. The seismic stratigraphy of the Lima basin shows gradual trenchward tilting during the Cenozoic (Clift et al., 2003), consistent with gradual erosion and subsidence increasing toward the trench, but not with the proposed wild fluctuations of the coast suggested here. Regarding the study of Ishman et al. (2003), these authors indicated that there were some bathyal sediments exposed on the Mejillones Peninsula in northern Chile. While this may be true, the majority of the Neogene in that region was deposited in shelf depths and strongly supports an approximately stationary shoreline (Hartley et al., 2000).

Even if the “deep water facies” of the Peruvian basins (Dunbar et al., 1990) are truly bathyal as suggested, then this would have the effect of increasing the rate of subduction erosion prior to inversion, and the degree of underplating since that time. This does not change the essential reconstruction of a switch in margin tectonics at 2 Ma. This switch was preceded by a period of slower tectonic erosion than is typical since the Mesozoic. Indeed, even if the shallow-water sediments exposed 40 km from the coast noted by Encinas et al. (2006) mark the landward limit of tectonic erosion, this would still preclude the rapid trench retreat rates of ~3 km/m.y. noted in many active margins (Clift and Vannucchi, 2004). We note that since 2 Ma, continued tectonic erosion in the trench region (Laursen et al., 2002; von Huene and Ranero, 2003) during basin inversion requires a steepening

of the forearc taper, not the margin-scale accretion proposed by Encinas and Finger. Current evidence points to synchronous accretion and erosion.

Encinas and Finger seem to be confused regarding the 170 km retreat of the coast at 33–35°S. We did not suggest that this retreat had to be caused by shallowing of the subducting slab, although this certainly happens (Kay et al., 2005) and may well have affected the forearc vertical tectonics. We only indicated that slab shallowing may play a part, as well as tectonic erosion, in driving arc retreat in this region. Separation of the two processes is difficult using the data at our disposal in this study.

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