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Comments

Reply to comment on "dynamic topography in South America" by Hechenleitnera, Fiorelli, Larrovere, Grellet-Tinnera, and Carignano

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A B S T R A C T

This is a Reply to Hechenleitner and collaborators Comment, who proposed a Cretaceous age for the whole Llanos Formation (central Argentina, Sierras Pampeanas Province), based on neosauropod fossils, instead of Miocene as originally proposed by Ezpeleta et al. (2006) and Dávila et al. (2007). However, red beds that underlay the thick paleosoils of the Llanos Formation provided nine detrital U–Pb Paleogene (62 Ma, earliest Cenozoic) ages on zircon grains (Astini et al., 2009; Ezpeleta 2009). On the base of this evidence, and other mammal remnant within the Sierras Pampeanas (where the Llanos Formation develops), we proposed this is a condensed unit with Mesozoic ages at the bottom and Mio-Pliocene (likely younger) to the top.

We appreciate the opportunity to debate the chronology of the Llanos Formation and its implications on the subsidence history of the distal Andean foreland in central Argentina.

The comment of Hechenleitner and collaborators reflects their major concern regarding the age of the Llanos Formation. The yargue for a Cretaceous (cf. Hünicken et al., 2001; Hünicken, 2005; Tauber, 2007; Grellet-Tinner and Fiorelli, 2010; Fiorelli et al., 2011a, 2011b, 2012, 2013) deposition based on neosauropod fossils, instead of Miocene as originally proposed by Ezpeleta et al. (2006) and Dávila et al. (2007). If this new proposal were correct, the Llanos Formation could not be used as a geological proxy for the Miocene dynamic topography in central Argentina (cf. Dávila and Lithgow-Bertelloni, 2013). However, our model was not based on this chronology or depends on comparison with this unit, and it is therefore still valid. However, we take this opportunity to clarify some aspects of the geochronology of the Llanos formation, which reinforce the conclusions of our modeling and geological comparisons.

Before discussing the chronology of the Llanos Formation, it is important to remember some crucial aspects of this unit carefully detailed by Ezpeleta et al. (2006). This is a very extensive, aggradational and, most important, condensed section formed by composite paleosoils, at least 300 m thick in the subsurface (Dávila et al., 2007). Coarse fluvial gravels are the parental material of the palesoils (Ezpeleta et al., 2006), where the Cretaceous fossil records (focus of this discussion) were found. The paleosoils, in turn, were correlated with other pedogenetic layers well exposed in the Cordoba (Avellaneda Formation) and San Luis (Las Carretas Formation) Ranges, to the East of the *Comment and Reply* regions (Ezpeleta et al., 2006; Dávila et al., 2007). The Llanos Formation and correlatives cover more than 200,000 km^2 and are comparable with the "supersols" of DeCelles et al. (2011).

The condensation characteristics of these paleosoil successions and widespread development within the distal foreland weaken the interpretation of a unique and unified Cretaceous age for the "Llanos paleosoils" as suggested by Hechenleitner and collaborators. The paleontological record described by this comment comes from two layers on two sites. These two layers correlate each other, between the southern Velasco Range (La Rioja canyon) and the western flank of the Llanos Ranges (near Tama town) (see locations in Dávila et al., 2007). But these Cretaceous beds do not correlate with the rest of the paleosoils (see chronology below), which are definitely Cenozoic.

We do not in fact deny a Cretaceous age, at least for these two sites. Hechenleitner et al., on the other hand, omitted very important geochronological data. Astini et al. (2009) and Ezpeleta (2009) dated a volcaniclastic horizon interlayered in a red bed succession, near Olta town (these red beds had been previously correlated with the Permian Patquia Formation, see Limarino et al., 1999). The Llanos paleosoils rest on these red beds. Detrital U–Pb ages on zircons provided nine Paleogene (62 Ma) ages from the red beds

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that underlay the Llanos Formation. Hence, at least in the Olta region, the "Llanos" paleosoils are not Cretaceous. Moreover, on the base of mammal remnants (see discussion in Ezpeleta et al., 2006), lithostratigraphic correlatives of the paleosoils were constrained to lie within the Mio-Pliocene, in Cordoba and San Luis Ranges, hundreds of kilometers to the South and East.

On the basis of this information, we propose two likely interpretations: (1) that the Cretaceous fossils are not *in situ* preservations, i.e., they were transported from Cretaceous outcrops (after fossil lithification) and the units are in fact younger than 62 Ma or, (2) that the paleosoil sequence is a condensed supersol, containing (at least) Cretaceous to Mio-Pliocene amalgamated horizons. The first is supported by the fact that the paleosoil parental material is fluvial, with paleocurrent indicators to the East and Cretaceous outcrops to the west (along the eastern flank of the Valle Fertil Range, Cerro Rajado Formation, Stipanicic and Bonaparte, 1972). The second is based on soil and paleosoil studies (e.g., Retallack, 2001) and the range of ages reported for the different "Llanos" paleosoil outcrops, including the detrital age of 62 Ma. We would like to note that because of such difficulties in interpretation same-rock lithostratigraphic correlations have been abandoned for regional reconstructions. Pedogenesis is a common process in continental environments and might be recurrent during the paleoenvironmental history of a continental area. In fact, the Sierras Pampeanas province (where these outcrops were studied), expose several levels of paleosoils and calcretes since at least the Late Paleozoic, when central Argentina became a continental environment. Consequently, we are inclined to the second interpretation, which also agrees with the tectonic setting, a distal foreland (from bulge to backbulge, cf. DeCelles and Giles, 1996). According to tectonic reconstructions (e.g., Ramos, 2009), the Sierras Pampeanas (where the Llanos paleosoils outcrop) would have been part of the distal foreland most likely since the Paleozoic. Therefore, we submit that the Llanos Formation, represented by thick paleosoil successions, is a condensed continental sequence formed between the Cretaceous (and likely older) and the Mio-Pliocene. Consequently, the hundreds of meters of Miocene paleosoils that overlay the Cretaceous layers represent a good proxy and geological evidence of the dynamic subsidence proposed by the Dávila and Lithgow-Bertelloni (2013) model.

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