

Late Miocene onset of the Amazon River and the Amazon deep-sea fan: Evidence from the Foz do Amazonas Basin: Reply

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J. Figueiredo^{1*}, C. Hoorn², P. van der Ven¹, and E. Soares¹

¹Petrobras, Av Rep do Chile 65 sala 1301, 20031-91, Rio de Janeiro, Brazil

²Institute for Biodiversity and Ecosystem Analysis, University of Amsterdam, 1098 SM Amsterdam, Netherlands

K. Campbell (2010) questions our data presented in Figueiredo et al., (2009) and proposes a late Pliocene (ca. 2.5 Ma) origin for the Amazon River. Here, we provide some clarifications and show that a late Miocene origin of the Amazon River is underpinned by a very robust data set. Firstly, Campbell comments that the absolute ages of the base and top of biozone NN9 differ from Lourens et al. (2004). The presented biostratigraphic zonation is based on information from Petrobras' data bank, and this in-house nannofossil biozonation scheme is somewhat different from the International zonation. Based on Lourens et al. (2004) and Raffi et al. (2006), the absolute age of Amazon River onset changes to 10.5 Ma, far from the 2.5 Ma proposed by Campbell's model.

Secondly, the Purus Arch originated as a NNW-SSE-trending graben, and inverted to a high during the Proterozoic (Brito Neves, 2002). Throughout the Phanerozoic, this structural feature alternatingly separated—or connected—the Solimões (western Amazonia) and Amazonas basins (eastern Amazonia) (Cunha et al., 2007; Wanderley Filho et al., 2007). The Solimões Formation—of Miocene age (Hoorn, 1993, and references therein)—is restricted to western Amazonia, therefore a reactivation of the Purus Arch must have happened during this time. Causal mechanism for this reactivation is ascribed to the Quechua I tectonic event which is coincident in age with deposition of the Solimões Formation (Noble et al., 1990, and references therein).

Thirdly, Campbell wrongly cites Lourens et al. (2004) who did not say "... sea level had reached nearly modern levels by the beginning of NN9" as stated in Campbell's Comment. Instead they said "Sea level gradually started to fall after 15 Ma, culminating in a dramatic drop around 10.5 Ma..." (p. 425), an age that coincides with the base of the biozone NN9 (Lourens et al., 2004; Raffi et al., 2006), and therefore supports our interpretation. More important, however, is the Petrobras' extensive data bank of seismic data and wells that attest that the early Tortonian sea level fell beyond the contemporary shelf edge over the entire Brazilian shoreline, giving support to the interpretation presented in our article.

Fourthly, Campbell's claim that there is poor correlation between terrigenous mass accumulation rates (TMAR) of the Amazon Fan and the Ceará Rise is unfounded. Distinct changes in TMAR and geochemical signals from 10 Ma onward are reported from the Ceará Rise (King et al., 1997; Dobson et al., 2001). King et al. (1997) remark on an overall increase of TMAR from the late Miocene onward with a particularly strong increase at 5.1 Ma. In addition, Dobson et al. (2001) specify that prior to 10 Ma deposition, sedimentation at the Ceará Rise was dominated by Archean-sourced shales, whereas post-Archean shales (i.e., of Andean origin) are deposited from 10 and 9 Ma onward, with a vast increase during the Pliocene. This coincides well with the geochemical changes and variations in sedimentation rates as described in Figueiredo et al., (2009).

Finally, Campbell suggests there is no overlap between our geochemical analysis and that of Basu et al. (1990) or McDaniel et al. (1997). The depleted-mantle average Nd model age (T_{DM}) of 1.46 Ga that Basu et al. (1990) found for the fluvial sands from the Madre de Dios basin does not

reflect the average age of the Brazilian continental crustal source, but, in fact, the average of the westernmost geochronological provinces of the Amazon craton (Tassinari and Macambira, 1999), and is not contaminated by older sources in the eastern Amazonia. To define the sedimentary provenance for the Amazon Fan we used McDaniel et al. (1997) as a benchmark, since they show results from a well-known Andean-sourced succession, which is similar to those from Well 1 presented in our article. In fact, as pointed out very well in Campbell's Comment, our T_{DM} mean age (1.591 Ga) is lower than the McDaniel et al. (1997) age (1.688 Ga). It favors our interpretation since it reflects a higher contribution from younger cratonic sources located in the westernmost Amazonia. In spite of this, we do thank Campbell for pointing out that the label of the axes in our Appendix 5b were inverted. The corrected version of Appendix 5 has been posted online.

In conclusion, all data we presented support our hypothesis for a late Miocene onset of the transcontinental Amazon River, and show that Campbell's model for the late Pliocene initiation of the Amazon River is flawed.

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*E-mail: picanco@petrobras.com.br