Forum

Neogene climate change and uplift in the Atacama Desert, Chile: COMMENT

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Rech et al. (2006) describe a variety of palaeosol characteristics from Miocene sections present along the southwest margin of the Calama Basin in the Atacama Desert of northern Chile. They identified a change in soil character from a calcic vertisol to an extremely mature gypsisol with pedogenic nitrate. The change in paleosol character is interpreted to record a decrease in precipitation related to a climatic shift from a semi-arid to hyper-arid climate some time between 19 and 13 Ma. This change is considered to be due to uplift of the Andes to an approximate elevation of 2000 m, creating an orographic barrier that prevented moisture from the South American summer monsoon entering the Atacama.

While it is likely that the Miocene gypsic paleosols do record a climate change, sedimentological and stratigraphic evidence from sections within the Calama Basin and elsewhere in the Atacama suggest that the significance and lateral extent of this change is limited and cannot be used to constrain Andean uplift, rain shadow development, and climate change. For example, sections within the Calama Basin that directly overlie the gypsic paleosols east and north of the sections studied by Rech et al. contain up to 55 m of alluvial conglomerate and sandstone (referred to as the Chiquinaputo Formation, Marinovic and Lahsen, 1984; May et al., 1999, 2005). These alluvial sediments are laterally equivalent to up to 85 m of palustrine limestones that are developed across much of the central part of the Calama Basin. The age of these sediments is constrained by interbedded ashes as being 8–3 Ma (May et al., 2005). The presence of alluvial gravels and sandstones conformably overlying the gypsic soils indicates that precipitation must have fallen directly on the eastern flank of the Calama Basin between 8 and 3 Ma.

Additional evidence for post-13 Ma alluvial activity on the west slope of the Andes and the Precordillera is provided by the sedimentary record throughout northern Chile (Hartley and Chong, 2002). In the Pampa del Tamarugal, alluvial and lacustrine sedimentation of the Quillagua Formation commenced between 7.3 and 6.3 Ma (Kiefer et al., 1997; Sáez et al., 1999). These include extensive alluvial fan deposits that were derived from catchments in the Precordillera. Sedimentation along the northwestern margin of the Salar de Atacama Basin commenced unconformably over early Miocene sediments around 10 Ma (Mpodozis et al., 2000). Importantly, in all of these examples, alluvial sediments were derived from adjacent catchments and deposited along basin flanks. Sedimentation was not restricted to valley systems, and groundwater recharge can be ruled out as a significant depositional process.

The study of Rech et al. (2006) cannot be used to infer a permanent climatic shift to hyperaridity generated by the rain shadow effect associated with Andean uplift, as: 1) the paleosols are aerially restricted, 2) they are overlain by a significant thickness of alluvial sediment deposited under a 'wetter' climate, and 3) sedimentological and stratigraphic data from adjacent basins indicate significant post-13 Ma alluvial activity, all of which indicate precipitation in catchments on the west flank of the Andes. Paleosol characteristics should not be used in isolation to constrain Andean uplift as they need to be integrated with other sedimentological and stratigraphic data in order to derive conclusions that can be applied to the whole of the Atacama. Additionally, in the Southern Hemisphere, a mountain range is not required to create hyperarid conditions on the western margin of a continent; however, such conditions are present beneath the downgoing limb of the Hadley cell (e.g., the hyperarid coastline of Namibia).

REFERENCES CITED

Hartley, A.J., and Chong, G., 2002, A late Pliocene age for the Atacama Desert: Implications for the desertification of western South America: Geology, v. 30, p. 43–46, doi: 10.1130/0091-7613(2002)030<0043:LPAFTA>2.0.CO;2.

Kiefer, E., Dörr, M.J., Ibbeken, I., and Götze, H.-J., 1997, The Arcas Fan, Pampa del Tamarugal, Northern Chile: Revista Geológica de Chile, v. 24, p. 165–185.

Marinovic, N. and Lahsen, A. 1984. Geología de la Hoja Calama, Escala 1:250.000: Santiago, Chile, Servicio Nacional de Geología y Minería, Carta Geológica de Chile, No. 58, 140 p.

May, G., Hartley, A.J., Stuart, F., and Chong, G., 1999, Tectonic signatures in arid continental basins: An example from the upper Miocene-Pleistocene, Calama basin, Andean forearc, northern Chile: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 151, p. 55–77, doi: 10.1016/S0031-0182(99)00016-4.

May, G., Hartley, A.J., Chong, G., Stuart, F., Turner, P., and Kape, S., 2005, Eocene to Pleistocene lithostratigraphy, chronostratigraphy and tectono-sedimentary evolution of the Calama Basin, northern Chile: Revista Geológica de Chile, v. 32, p. 33–60.

Mpodozis, C., Blanco, N., Jordan, T.E., and Gardeweg, M.C., 2000, Estratigráfia y deformación del Cenozoico tardio en la región norte de la Cuenca del Salar de Atacama: La zona de Vilama-Pampa Vizcachitas: Actas IX Congresso Geológico Chileno, Puerto Varas, v. 2, p. 598–603.

Rech, J.A., Currie, B.S., Michalski, G., and Cowan, A.M., 2006, Neogene climate change and uplift in the Atacama Desert, Chile: Geology, v. 34, p. 761–764, doi: 10.1130/G22444.1.

Sáez, A., Cabrera, L., Jensen, A., and Chong, G., 1999, Late Neogene lacustrine record and palaeogeography in the Quillagua-Llamara basin, Central Andean fore-arc (northern Chile): Palaeogeography, Palaeoclimatology, Palaeoecology, v. 151, p. 5–37, doi: 10.1016/S0031-0182(99)00013-9.

REPLY: doi: 10.1130/G23810Y.1

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We welcome comments by Hartley regarding our Neogene climate reconstruction of the Atacama Desert (Rech et al., 2006) and the opportunity to further discuss the resolution and sensitivity of soils and sedimentological deposits for inferring hyperaridity in the geologic record. In regard to our Calama Basin paleosol record, Hartley agrees that the mid-Miocene transition from rooted and gleyed calcic vertisols to salic gypsisols with pedogenic nitrate likely records a change in climate. Hartley states, however, that the significance and lateral extent of this change is limited and therefore cannot be used to constrain Andean uplift, rain shadow development, or regional climate change. Moreover, Hartley argues that we do not integrate our paleosol data with the sedimentological and stratigraphic data from the region, which indicate wetter conditions during the Miocene. The sedimentary and stratigraphic evidence Hartley cites to suggest wetter conditions during the Miocene include 1) ~55 m of alluvial conglomerate and sandstone that overlie the Barros Arana gypsisol, 2) evidence of post-13 Ma alluvial activity along the west flank of the Andes, and 3) the 85-m-thick unit of palustrine carbonate (Opache Formation) deposited in the central part of the Calama Basin between 8 and 3 Ma.

Our fundamental disagreement with Hartley concerns the sensitivity and robustness of various sedimentological deposits that have been used to reconstruct long-term climate change in the Atacama Desert (Hartley and Chong, 2002; Hartley, 2003; Hartley et al., 2005). We agree with Hartley's argument that alluvial deposits that overlie the Barros Arana gypsisol, as well as post-13 Ma alluvial deposits along the west slope of the Andes, indicate precipitation on the adjacent catchments. Occasional precipitation events occurred in the past as they do today in the Atacama, and large precipitation events are capable of eroding and depositing material downstream. This is especially true in areas of pronounced relief, such as the western flank of the Andes, or in areas influenced by tectonically induced changes in base level. We therefore find it difficult to use the presence and thickness of alluvial deposits at a mountain front to infer past climatic regimes. Hartley also suggests that the Upper Miocene–Piocene palustrine Opache Formation, deposited from ~8–3 Ma across the central part of the Calama Basin, reflects wetter conditions. Marshes and wetlands fed by extralocal precipitation in the Andes are common in the Atacama today (e.g., Rech et al., 2002) and their mere presence in the geologic record cannot be used to infer wetter conditions. Analysis of the Opache Formation by May et al. (1999) led these authors to conclude that tectonic influences on basin accommodation development and drainage patterns are the primary control on the formation of these paludal deposits.

We specifically chose to use soils and paleosols in the Atacama Desert to reconstruct climate change because there is a direct relationship between climate and soils in this region today. The hyperarid core of the Atacama Desert contains thick soils cemented by nitrate, chloride, and sulfate salts, whereas soils on the outer margins of the Atacama transition to predominately sulfate and carbonate soils with greater precipitation (Rech et al., 2003; Ewing et al., 2006). We suggest that the relationship between soil salts and precipitation is a sensitive recorder of precipitation (cf. Amit et al., 2006), as long as soil salts originate from eolian additions and not from capillary rise from groundwater. The transition from calcic vertisol soils with root traces and gleyed horizons (which do not form in the Atacama today) to the Barros Arana gypsisol with soil nitrate represents a dramatic decrease in precipitation in the Calama Basin during the mid-Miocene. We suggested in our article that this dramatic decrease in precipitation was likely caused by Andean uplift to >2 km and the development of the Andean rain shadow. We argue for the development of an Andean rain shadow by this time because the Barros Arana gyspsisol represents a period of prolonged (10^6 years) hyperaridity (<20 mm/yr precipitation) on the eastern margin of the Atacama. It is difficult to imagine that this hyperaridity was maintained through orbital and millennial climate variations during the mid-Miocene without the presence of an Andean rain shadow.

Hartley contends that, in the Southern Hemisphere, a mountain range is not required to create hyperarid conditions on the western margin of a continent, and notes the hyperarid coastline of the Namib Desert. However, it is unclear to us if hyperarid conditions were indeed maintained in the Namib during Quaternary climatic oscillations. If we examine the record of soil development in the Namib, thick layers of soil carbonate underlie gypsic horizons (Bao et al. 2001), which suggests to us that hyperarid conditions were not maintained through Quaternary climate oscillations.

We do agree with Hartley that the paleosols in the Calama Basin only represent one data point, and that our results need to be replicated over a broader spatial scale and with different paleoclimatic proxies to truly reconstruct the development of an Andean rain shadow. We are currently working with paleosols and stable isotopic records over a broader spatial region to this end. We can also integrate these data within the broader context of sedimentological data from the Atacama Desert, if a climatic signal can be teased apart from tectonic influences in the Andean forearc.

REFERENCES CITED

Amit, R., Enzel, Y., and Sharon, D., 2006, Permanent Quaternary hyperaridity in the Negev, Israel, resulting from regional tectonics blocking Mediterranean frontal systems: Geology, v. 34, p. 509–512, doi: 10.1130/G22354.1.

Bao, H., Thiemens, M.H., and Heine, K., 2001, Oxygen-17 excesses of the Central Namib gypcretes: Spatial distribution: Earth and Planetary Science Letters, v. 192, p. 125–135, doi: 10.1016/S0012-821X(01)00446-0.

Ewing, S.A., Sutter, B., Owen, J., Nishiizumi, K., Sharp, W., Cliff, S.S., Perry, K., Dietrich, W., McKay, C.P., and Amundson, R., 2006, A threshold in soil formation at Earth's arid-hyperarid transition: Geochimica et Cosmochimica Acta, v. 70, p. 5293–5322, doi: 10.1016/j.gca.2006.08.020.

Hartley, A.J., 2003, Andean uplift and climate change: Geological Society of London Journal, v. 160, p. 7–10.

Hartley, A.J., and Chong, G., 2002, Late Pliocene age for the Atacama: Implications for desertification of western South America: Geology, v. 30, p. 43–46, doi: 10.1130/0091-7613(2002)030<0043:LPAFTA>2.0.CO;2.

Hartley, A.J., Chong, G., Houston, J., and Mather, A.E., 2005, 150 million years of climate stability: Evidence from the Atacama Desert, northern Chile: Geological Society of London Journal, v. 162, p. 421–444, doi: 10.1144/0016-764904-071.

May, G., Hartley, A.J., Stuart, F.M., and Chong, G., 1999, Tectonic signatures in arid continental basins: An example from the Upper Miocene-Pleistocene, Calama Basin, Andean forearc, northern Chile: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 151, p. 55–77, doi: 10.1016/S0031-0182(99)00016-4.

Rech, J.A., Quade, J., and Betancourt, J.L., 2002, Late Quaternary paleohydrology of the central Atacama Desert (lat 22°–24°S), Chile: Geological Society of America Bulletin, v. 114, p. 334–348, doi: 10.1130/0016-7606(2002) 114<0334:LQPOTC>2.0.CO;2.

Rech, J.A., Quade, J., and Hart, W.S., 2003, Isotopic evidence for the origin of Ca and S in soil gypsum, anhydrite, and calcite in the Atacama Desert, Chile: Geochimica et Cosmochimica Acta, v. 67, p. 575–586, doi: 10.1016/S0016-7037(02)01175-4.

Rech, J.A., Currie, B.S., Michalski, G., and Cowan, A.M., 2006, Neogene climate change and uplift in the Atacama Desert, Chile: Geology, v. 34, p. 761–764, doi: 10.1130/G22444.1.