# Miocene-Pliocene climate change in the Peru-Chile Desert

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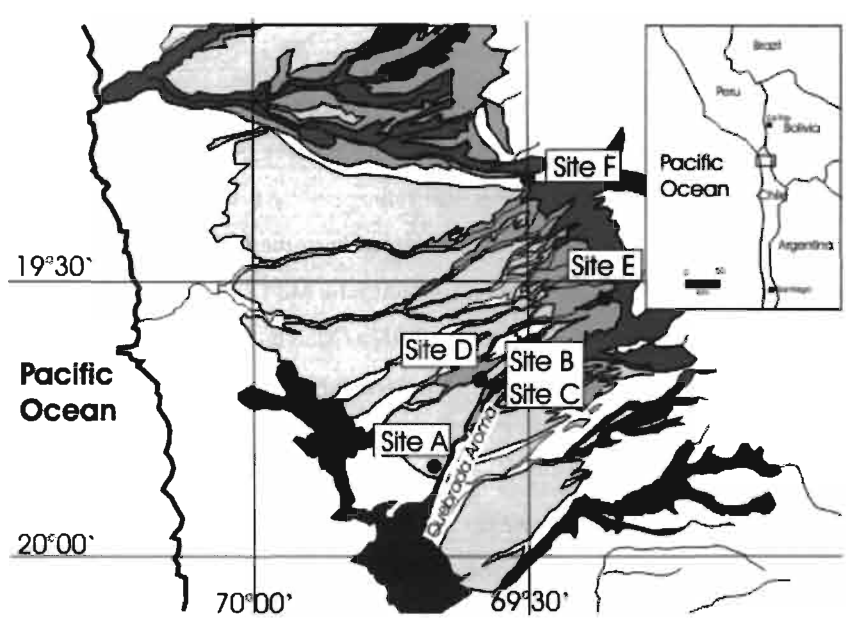
The exact time at which the climate in the Peru-Chile Desert became hyperarid is a topic of vigorous debate with ages ranging from 25 Ma (Dunai et al. 2005), 14 Ma (Alpers & Brimhall 1988) and 3 Ma (Hartley & Chong 2002). Recent mapping of alluvial fans in the Peru-Chile Desert by the authors using Landsat data between 16.3°S and 23°S (Fig 1) has identified several distinct erosional and depositional surfaces. By combining previous work on pediplains, sedimentology, supergene enrichment ages of porphyry copper deposits and cosmogenic $^{21}Ne$ exposure ages with new cosmogenic $^{3}He$ data, we interpret these surfaces to have formed primarily at 21 Ma, 14 Ma and 3 Ma.

The oldest pediplain mapped is present throughout the Peru-Chile Desert and can be correlated with (1) pediplains in southern Peru (e.g. Altos de Camilaca <22.7 Ma; Tosdal et al. 1984), (2) unconformities in the Calama basin (ca. 20 Ma; May et al. 1999; 2005) and (3) the cessation of supergene enrichment of porphyry copper deposits around 21 Ma in several areas of the Atacama Desert (Sillitoe & Mckee 1998). This can also be related to recent $^{21}Ne$ cosmogenic isotope data from the coastal cordillera that show a peak at 23 Ma (Dunai et al. 2005).

Cosmogenic $^{3}He$ exposure ages have been determined in pyroxenes from boulders of basalt that are present on a surface within the Longitudinal Valley (Fig. 3). The 27-22 Ma exposure age derived from these boulders supports previous evidence for a 20-21 Ma age of increased aridity that resulted in either a decrease or cessation of supergene enrichment in several areas of northern Chile (Sillitoe & Mckee 1998). This change in climate coincides with two significant events, notably an important phase of Andean uplift (Isacks 1988) and opening of the Drake Passage (23 Ma).

A second younger surface was mapped throughout the area and overlaps with a regional pediplain dated by Tosdal et al (1984) at 14 Ma. This surface, when traced further south within the Peru-Chile Desert, correlates with surfaces recognised by several other authors, including the erosion surface on the Oxaya block (Wörner et al 2002). The age also correlates with regional unconformities further south in the Salar de Atacama (Kape 1996; May et al. 1999) and a peak in cosmogenic isotope exposure age data presented by Dunai et al (2005). Two samples from the lower terrace of Quebrada Aroma yield exposure ages of 14-16Ma (Fig. 2 & 3). These all indicate that sufficient precipitation continued, but at a decreasing rate, with deposition of sediments in areas adjacent to the main rivers up to 14 Ma. After this time a second increase in aridity resulted in development of a further relict pediplain and ended the majority of the remaining supergene enrichment in the Atacama, including Cerro Colorado, which is located on the preserved pediplain.

**Fig.1** (right hand corner) Study area located upon Peru-Chile desert. **Fig.2** (right) Location of sample sites within the Longitudinal valley. Black circles with numbers show location of samples. Surface 1 formed up until 21Ma, Surface 2 formed from 21Ma till 14Ma and Surface 3 terraces formed between 14Ma and 3Ma. Represents recent sedimentation.



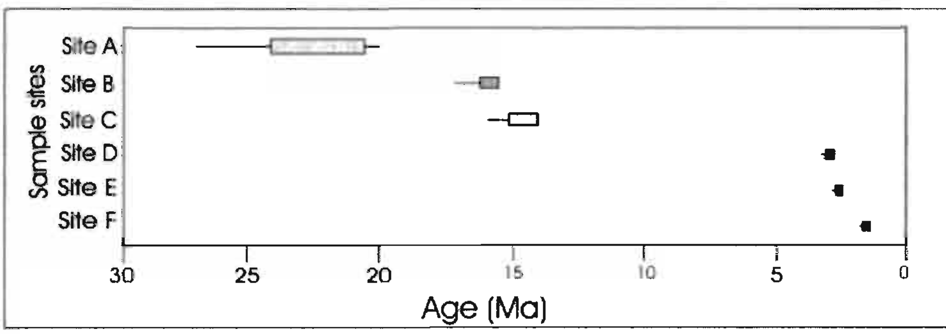




**Fig. 3** Results of cosmogenic analysis. Thin black lines indicate range of possible ages based on cosmogenic isotope data. Shaded boxes indicate more precise ages calculated using uplift rates of Victor et al [10]. Shading in boxes corresponds to surfaces 1-3 identified in Fig. 2.

Surfaces that are younger than 14 Ma cannot be traced over the entire area. The most extensive of these younger surfaces is developed south of 19°S on distal alluvial fan deposits and limestones within the Calama basin that May et al (1999) argue were deposited at 3-5 Ma. North of 19°S an erosional terrace is found proximal to the main rivers and has until now, been undated. Cosmogenic $^3He$ exposure ages of 2.96 Ma and 2.67 Ma were obtained from boulders taken from this surface (Figs 2 and 3). These ages indicate that substantial precipitation must have taken place in the Precordillera in order for deposition to occur in the south of the study area, and for erosion to form terraces in the north of the area. The difference in depositional style from the south to north is likely to be due to a variation in base-level. Rivers in the north drain directly to the Pacific and dissect the Coastal Cordillera, in contrast to those in the south, which are endorheic and drain directly into the Central Depression, resulting in a base-level difference of 1000 m from south to north. At 3 Ma a final drop in water table level is considered to have taken places at which point sedimentation in the Calama area ceased, while in the north this drop in base level allowed the final incision into the 3 Ma terrace to form the incised river channels seen today.

The cosmogenic isotope results presented here show that the climate in the Central Depression has not been sufficiently humid for any substantial erosion to have occurred in the Peru-Chile desert since at least 21 Ma. However, enough precipitation was still falling on the Precordillera and Western Cordillera to create terraces in areas proximal to the main rivers, sedimentation in the Calama/Salar de Atacama basin and to allow supergene enrichment in porphyry copper deposits until 14 Ma (Sillitoe & Mckee 1998). Localised enrichment in a few porphyry copper deposits continued until 6Ma (March et al.1997). After this time sedimentation continued on a smaller scale in the Calama Basin with terrace development continuing until at least 3 Ma.

## CONCLUSIONS

These results show that the western part of Peru-Chile desert (Coastal Cordillera, western Central Depression) has been arid for at least 22 Ma. The Andes have been uplifting since at least the Oligocene but did not produce a significant orographic barrier until the mid to late Miocene (Lamb & Davis 2003). Andean uplift could not be the cause of aridity in the Peru-Chile desert and it is most likely that conditions in the Atacama are, and have always been, arid due to its geographical position on the west coast of a large land mass (e.g. Hartley et al. 2005).

The surfaces identified here are merely superimposed global climate events on an already arid environment. In areas to the south of 19°S these are represented by telescoping of alluvial fans out into the Atacama basin while north of 19°S the dissection of the Coastal Cordillera by main rivers allowed these surfaces to develop as a number of terraces cut into older pediplains. Finally, this research shows a potential correlation between pediplain age and the age of supergene enrichment associated with these surfaces.

## References


Alpers, C. & Brimhall, G. 1988. Middle Miocene climatic change in the Atacama Desert, northern Chile: Evidence from supergene mineralization at La Escondida. Bulletin of the Geological Society of America, 100, 1640-1656.

Darke, K. 1996. Supergene mineralization in the gold-rich Bolivian polymetallic vein deposits. PhD Thesis, University of Aberdeen

Dunai, T.J., López. G.A.G. & Juez-Larré, J. (2005) Oligocene/Miocene age of aridity in the Atacama Desert revealed by exposure dating of erosion sensitive landforms. Geology (in press)

Hartley, A.J. 2003. Andean uplift and climate change. Journal of the Geological Society, London, 160, 7-10.

Hartley, A.J. & Chong, G. 2002. A late Pliocene age for the Atacama Desert: Implications for the desertification of western South America. Geology, 30, 43-46.

Hartley, A.J., Chong, G., Houston, J. & Mather A.E. 2005. 150 Million Years of Climatic Stability – Evidence from the Atacama Desert, northern Chile. Journal of the Geological Society, London, 162, (in press).

Isacks, B.L., 1988. Uplift of the Central Andean Plateau and bending of the Bolivian Orocline. Journal Geophysical Research, 93, 3211-3231.

Kape, S.J. 1996. Basin analysis of the Oligo-Miocene Salar de Atacama, Northern Chile. PhD Thesis, University of Birmingham, U.K.

Lamb, S. & Davis, P. 2003. Cenozoic climate change as a possible cause for the rise of the Andes. Nature, 425, 792-797.

Marsh TM., Einaudi MT. & McWilliams M. 1997. $^{40}Ar/^{39}Ar$ geochronology of Cu-Ar and Su-Ag mineralization in the Potrerillos district, Chile. Economic Geology, 92, 784-806.

May, G., Hartley, A.J., Stuart, F.M. & Chong, G. 1999. Tectonic signatures in arid continental basins: an example from the Upper Miocene-Pleistocene, Calama Basin, Andean forearc, northern Chile. Palaeogeography, Palaeoclimatology and Palaeoecology, 151, 55-77.

May, G., Hartley, A.J., Chong, G., Stuart, F., Turner, P. & Kape, S. 2005. Oligocene to Pleistocene Lithostratigraphy of the Calama Basin, northern Chile. Revista Geológica de Chile, 32, 33-60.

Sillitoe, R. & McKee, H. 1996. Age of supergene oxidation and enrichment in the Chilean porphyry copper province. Economic Geology, 91, 164-179.

Tosdal, R.M., Clark, A.H. & Farrar, E. 1984. Cenozoic polyphase landscape and tectonic evolution of the coastal Occidental, southernmost Peru. Bulletin of the Geological Society of America, 95, 1318-1332.

Victor, P. Oncken, O., Glodny, J. 2004. Uplift of the Western Altiplano plateau: Evidence from the Precordillera between 20° and 21° (northern Chile). Tectonics, 23, 1-24.

Wörner, G., Uhlig, D., Kohler, I. & Seyfried. H. 2002. Evolution of the West Andean Escarpment at 18°S (N. Chile) during the last 25 Ma: uplift, erosion and collapse through time. Tectonophysics, 345, 183-198.