Quaternary Science Reviews xxx (2014) 1–3

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

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Reply to the comment by A. Sáez et al. on 'Climate in the Western Cordillera of the Central Andes over the last 4300 years' by Engel et al. (2014)

The interpretation of the insoluble particles origin in the Central Andean ice cores represents a research challenge worth further debate. The enhanced dust concentration in the Quelccaya ice cap was originally associated with periods of dry conditions that favour the mobilization of dust, particularly from drying lakes and wetlands, and its accumulation on glaciers (Thompson, 1980). The relation between moisture conditions and dust content in the Andean ice cores was subsequently validated for longer time-scales and insoluble mineral dust particles were used as the indicator of regional aridity over the Lateglacial and Holocene (e.g., Thompson et al., 2003 and references therein; Knüsel et al., 2005; Vimeux et al., 2009; Kellerhals et al., 2010). Also, the dust record from the Sajama ice cap was initially attributed to the changes in climate conditions, net ice accumulation and local volcanic activity (Thompson et al., 1998). Subsequently, volcanic eruptions were denoted as a primary source of dust in the Sajama ice core based on the results of X-ray fluorescence and the advanced geochemical analyses from the lake Chungará sedimentary records (Moreno et al., 2007; Giralt et al., 2008). Sáez et al. emphasize the non-climatic origin interpretation of dust particles in the Sajama core in their recent comment (Sáez et al., 2015). Authors develop their reasoning based on alleged discrepancy between the number of dust/arid events recorded in the Carhuasanta peat (Engel et al., 2014) and Sajama ice cores (Thompson et al., 1998, 2000). The argument stated by Sáez et al. (2015) that Sajama ice dust record reflects mainly volcanic activity sounds convincing. However, it does not seem to be directly pertinent to questioning the interpretation of the Carhuasanta peat core (Engel et al., 2014).

In our study, we used two main proxies for the interpretation of palaeoclimate conditions in the peat core from the Carhuasanta Valley at the foot of Nevado Mismi in the southern Peruvian Andes (located ~400 km NW of Chungará Lake and Nevado Sajama, Fig. 1). The first proxy, the stable carbon isotope composition ($\delta^{13}C$) of *Distichia* peat, reflects mainly the relative variation of the mean air temperature during subsequent growing seasons (Skrzypek et al., 2011), and allows reconstructions of palaeotemperature changes. The second proxy, peat organic carbon concentration (C % wt), records mainly wetness in the valley, directly corresponding to the changes in runoff in the upper part of the catchment. In the sampling location, it reflects mainly the changes in precipitation and to lesser extent the changes of temperature (melting of episodic snow cover). *Distichia* plant grows in a semiaquatic environment and *Distichia* peat consists of macrofossil formed by continuously growing plants, similar to *Sphagnum* peat bogs (e.g., Engel et al., 2010). The surface of the peat bog is occasionally flooded and mineral particles deposited on the plants reduce relative carbon percentage. Therefore, C% signature indicates relative changes in wetness. The $\delta^{13}C$ value was used in our study as a primary proxy for the reconstruction of relative temperature variations over the last ~4 ka years and subdivision of climatic periods in the Carhuasanta record (Fig. 11 in Engel et al., 2014). Therefore, the seven periods (A–G) described in the Carhuasanta peat core reflect temperature variations and not wetness changes as perceived by Sáez et al. (2015) in their comment.

The correlation between the Carhuasanta core and the Nevado Sajama and Chungará records is complicated by their location in

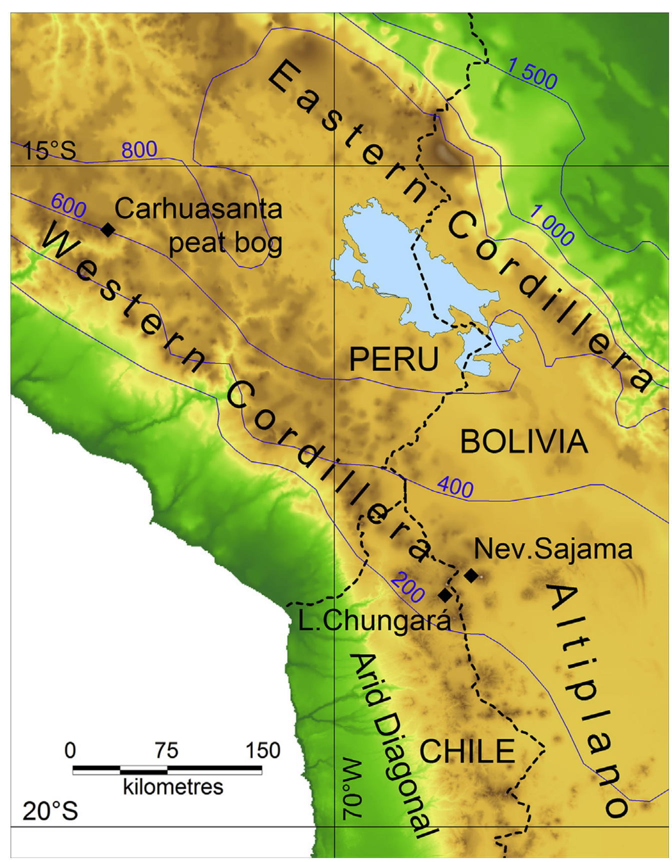

Fig. 1. Location map for the sites discussed in the text. Isohyets, given as the mean precipitation in mm/yr (in blue) adopted from Blard et al. (2009). The distance between Carhuasanta and Lake Chungará is ~400 km. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

DOI of original article: http://dx.doi.org/10.1016/j.quascirev.2014.12.005.

http://dx.doi.org/10.1016/j.quascirev.2014.12.006

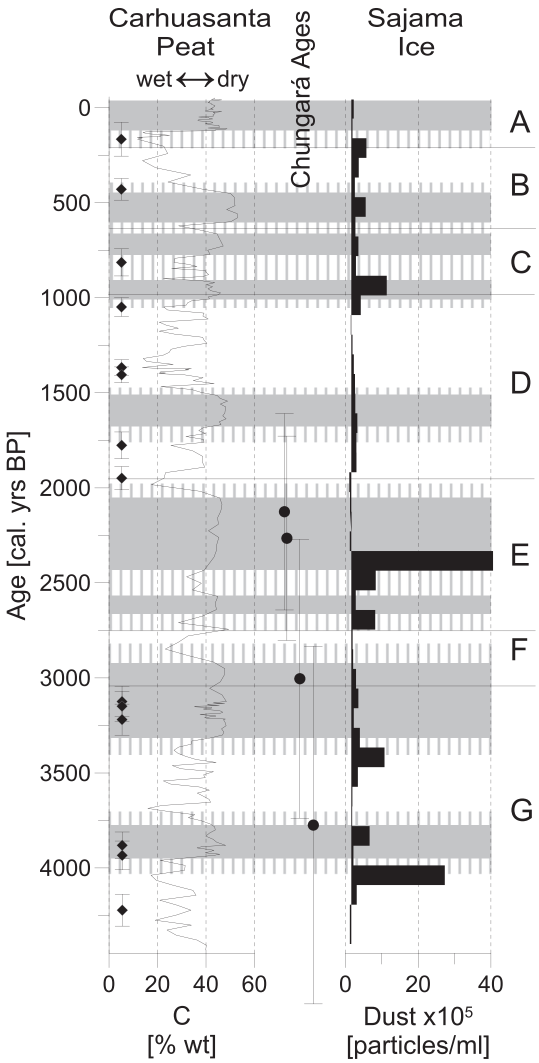

Fig. 2. Comparison of drier phases (grey shading) in the Carhuasanta peat core based on Engel et al. (2014) with the Sajama dust record (Thompson et al., 1998). The diamonds with error bars and grey vertical hatch show AMS ^{14}C calibrated ages and the uncertainties of the Carhuasanta record (from Engel et al., 2014). The circles with error bars for the Chungará record after Giralt et al. (2008). The A–G divisions are palaeotemperature periods as in Engel et al. (2014).

different climate zones. The Carhuasanta valley is cut in the north-facing slope of the continental divide with the precipitation values between 600 and 800 mm per year (Fig. 1). By contrast, the Nevado Sajama and Chungará sites are located close to the northern tip of an extremely arid zone (so-called the Arid Diagonal) that separates regions with different atmospheric circulation and moisture sources (Zech et al., 2009). The Sajama and Chungará sites receive <350 mm and the inter-annual precipitation variability in this region is high (Hardy et al., 1998; Moreno et al., 2007). The precipitation and ice accumulation on the Sajama ice cap is thus limited to few weeks per year (Hardy et al., 2003). For these reasons, not necessarily the same climatic conditions were recorded over the past thousands of years in these two regions. Moreover, age uncertainties preclude precise aligning of the records. The Late Holocene chronology of the Chungará record relevant to our study period of the last 4.3 ka is based only on four AMS ages distributed between 2050 and 3645 ka (Giralt et al., 2008). Age uncertainties of these radiocarbon dates range between 500 and 910 years being an order of magnitude larger compared to the uncertainties of the Carhuasanta record (Fig. 2). Therefore, only approximate aligning of the records will be possible using advanced numerical approaches (e.g., Blaauw, 2012).

In summary, we agree that the palaeoclimate implications of the Sajama ice core record are challenging and that further research is necessary for its validation and integration with other records from the region. Similarly, temporal changes in local moisture changes in the Central Andes and forcing mechanisms of these changes remain partly unknown and need to be investigated in greater details. On the contrary, we disagree with the Sáez et al. (2015) critique of Carhuasanta record interpretation (Engel et al., 2014). Primarily because palaeotemperature periods (A–G, Engel et al., 2014) do not necessarily correspond with aridity periods (Sáez et al., 2015) and also due to the Late Holocene age uncertainties of the Chungará record (Giralt et al., 2008) that prevent robust cross correlation of individual climatic periods.

References

Blard, P.H., Lavé, J., Farley, K., Fornari, M., Jimenez, N., Ramirez, V., 2009. Late local glacial maximum in the Central Altiplano triggered by cold and locally-wet conditions during the paleolake Tauca episode (17-15 ka, Heinrich 1). Quat. Sci. Rev. 28, 3414–3427.

Blaauw, M., 2012. Out of tune: the dangers of aligning proxy archives. Quat. Sci. Rev. 36, 38–49.

Engel, Z., Skrzypek, G., Paul, D., Drzewicki, W., Nývlt, D., 2010. Sediment lithology and stable isotope composition of organic matter in a core from a cirque in the Krkonoše Mountains, Czech Republic. J. Paleolimnol. 43 (4), 609–624.

Engel, Z., Skrzypek, G., Chuman, T., Šefrna, L., Mihaljevič, M., 2014. Climate in the Western Cordillera of the Central Andes over the last 4300 years. Quat. Sci. Rev. 99, 60–77.

Giralt, S., Moreno, A., Bao, R., Sáez, A., Prego, R., Valero-Garcés, B.L., Pueyo, J.J., González-Sampériz, P., Taberner, C., 2008. A statistical approach to disentangle environmental forcings in a lacustrine record: the Lago Chungará case (Chilean Altiplano). J. Paleolimnol. 40 (1), 195–215.

Hardy, D.R., Vuille, M., Braun, C., Keimig, F., Bradley, R.S., 1998. Annual and daily meteorological cycles at high altitude on a tropical mountain. Bull. Am. Met. Soc. 79, 1899–1913.

Hardy, D.R., Vuille, M., Bradley, R.S., 2003. Variability of snow accumulation and isotopic composition on Nevado Sajama, Bolivia. J. Geophys. Res. 108 (D22), 4693.

Kellerhals, T., Brütsch, S., Sigl, M., Knüsel, S., Gäggeler, H.W., Schwikowski, M., 2010. Ammonium concentration in ice cores: a new proxy for regional temperature reconstruction. J. Geophys. Res. 115 (D16), D16123.

Knüsel, S., Brütsch, S., Henderson, K.A., Palmer, A.S., Schwikowski, M., 2005. ENSO signals of the twentieth century in an ice core from Nevado Illimani, Bolivia. J. Geophys. Res. 110 (D1), D01102.

Moreno, A., Giralt, S., Valero-Garcés, B., Sáez, A., Bao, R., Prego, R., Pueyo, J.J., González-Sampériz, P., Taberner, C., 2007. A 14 kyr record of the tropical Andes: the Lago Chungará sequence (18°S, northern Chilean Altiplano). Quat. Int. 161 (1), 4–21.

Sáez, A., Giralt, S., Hernandéz, A., Bao, R., Pueyo, J.J., Moreno, A., Valero-Garcés, B.L., 2015. Comment on 'Climate in the Western Cordillera of the Central Andes over the last 4300 years'. Quat. Sci. Rev..

Skrzypek, G., Engel, Z., Chuman, T., Šefrna, L., 2011. Distichia peat - a new stable isotope paleoclimate proxy for the Andes. Earth Planet. Sci. Lett. 307 (3–4), 298–308.

Thompson, L.G., 1980. Glaciological investigations of the tropical Quelccaya Ice Cap, Peru. J. Glaciol. 25 (91), 69–84.

Thompson, L.G., Davis, M.E., Mosley-Thompson, E., Sowers, T.A., Henderson, K.A., Zagorodnov, V.S., Lin, P.-N., Mikhalenko, V.N., Campen, R.K., Bolzan, J.F., Cole-Dai, J., Francou, B., 1998. A 25,000-year tropical climate history from Bolivian ice cores. Science 282 (5395), 1858–1864.

Thompson, L.G., Mosley-Thompson, E., Henderson, K.A., 2000. Ice core palaeoclimate records in tropical South America since the last glacial maximum. J. Quat. Sci. 15 (4), 377–394.

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Lin, P.N., Henderson, K.A., Mashiotta, T.A., 2003. Tropical glacier and ice core evidence of climate change on annual to millennial time scales. Clim. Change 59, 137–155.

Vimeux, F., Ginot, P., Schwikowski, M., Vuille, M., Hoffmann, G., Thompson, L.G., Schotterer, U., 2009. Climate variability during the last 1000 years inferred from Andean ice cores: a review of methodology and recent results. Palaeogeogr. Palaeoclimatol. Paleoecol. 281, 229–241.

Zech, R., Smith, J., Kaplan, M.R., 2009. Chronologies of the Last Glacial Maximum and its termination in the Andes (~10–55°S) based on surface exposure dating. In: Vimeux, F., Sylvestre, F., Khodri, M. (Eds.), Past Climate Variability in South America and Surrounding Regions. Springer, Heidelberg, pp. 61–87.

Please cite this article in press as: Engel, Z., Skrzypek, G., Reply to the comment by A. Sáez et al. on 'Climate in the Western Cordillera of the Central Andes over the last 4300 years' by Engel et al. (2014), Quaternary Science Reviews (2014), http://dx.doi.org/10.1016/j.quascirev.2014.12.006

Zbyněk Engel*
Charles University in Prague, Praha, Czech Republic

Grzegorz Skrzypek
The University of Western Australia, Crawley, Australia

* Corresponding author.
E-mail address: engel@natur.cuni.cz (Z. Engel).

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