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K-Ar and $^{40}Ar/^{39}Ar$ ages from supergene minerals in northern Chile: Prevalence of humid climate and tectonic uplift until the Upper Miocene in the Atacama Desert

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Introduction

Supergene mineral generation requires a balance between a) depression of the water table, by tectonically induced uplift or desiccation, and resultant exposure of underlying sulphides to the effects of oxidative weathering and b) at least moderate precipitation (> 10 cm/yr, semiarid climate) (Clark et al., 1990). Previous studies in porphyry copper deposits along of Atacama Desert, document Oligocene to Miocene ages for supergene minerals suggesting a shift of hypearidity at Middle Miocene (~14 Ma) when supergene activity ceased (Alpers and Brimhall, 1988; Sillitoe and Mc Kee, 1996, Bouzari and Clark, 2002). Geomorphologic evidence for the onset of the hyperaridity is provided by the preservation of the extensive Palaeogene to late Miocene pediments surfaces, which developed in a semiarid climate in direct response to uplift events. Ages for these surfaces suggest that the main period of pedimentation finished at ~9 Ma in Coastal Cordillera, Central Depression and Precordillera areas of Atacama Desert (e.g. Mortimer, 1980; Cornejo et al., 1999; Bissig et al., 2002; Dunai, pers. com). On the other hand, Hartley and Chong (2002) suggest pediplain surfaces exposition were controlled more by geographic location than climatic conditions. These authors observe that in some places of Central Depression, pediment surfaces are covered by upper Miocene or younger sediment. Nature and timing of changes of sediments suggest that a semiarid climate persisted from 8 to 3 Ma, which was punctuated by a phase of increased aridity at ca. 6 Ma and followed by the establishment of the present-day hyperarid climate between 4 and 3 Ma.

In this study we document new K-Ar and $^{40}Ar/^{39}Ar$ ages for supergene alunite and Mn-oxides from Central Depression in Atacama Desert of Northern Chile at 25°S (Fig. 1), and discuss their relationship with tectonic and climatic factors. Climatic effects on supergene mineral formation can be related to global or local climatic changes such as global desiccation increase of aridification pulses and the occurrence of humid phases trend (e.g. Vasconcelos, 1999), whereas tectonic factors such as local uplift, exhumation, and associated fracturing of rocks, provided fresh mineral surfaces for percolating meteoric fluids that induced subsequent weathering under relatively humid conditions (e.g. Hautmann and Lippolt, 2000).

Results

Twenty two samples of supergene alunite and nine of supergene K-bearing Mn-oxides, were analyzed by K-Ar and $^{40}Ar/^{39}Ar$ methods in the Laboratory of Geochronology of Servicio Nacional de Geologia y Mineria in Chile (see Arancibia et al, for details). Well-defined plateau and/or isochron ages were obtained in most samples with minor recoil effects and contaminants presence. $^{40}Ar/^{39}Ar$ ages of supergene alunite range between

14.7±0.6 and 27.3±0.3 Ma, while Mn-oxides have ages from 9.8±0.8 to 14.0±0.3 Ma. Figure 2 shows the relation between best age estimation of supergene minerals and elevation for twenty samples. A probability diagram, which contains K-Ar and $^{40}Ar/^{39}Ar$ ages of both supergene alunite and Mn-oxide minerals, is shown in Figure 3. Results suggest that supergene minerals precipitated between *ca.* 33 and 9 Ma and two significant changes in geological and environmental conditions were recorded at 14 Ma and 9 Ma, when alunite and Mn-oxide precipitation ended.

Discussion and Conclusions

Supergene mineral precipitation ages suggest that supergene oxidation in Central Depression at 25°S was product of long-term weathering extending from the Oligocene to Upper Miocene. The abrupt end of supergene alunite generation at 14 Ma is similar to observed by previous studies in porphyry copper deposits in Precordillera of Northern Chile (Sillitoe and Mc Kee, 1996; Alpers and Brimhall, 1988; Bouzari and Clark, 2002). On the other hand, favourable conditions for the precipitation of Mn-oxides in the studied area, only existed after 14 Ma., and prevailed at least until 9 Ma. End of alunite precipitation was probably related to complete pyrite oxidation, whereas end of Mn-oxides production would document the end of humid conditions.

Most obtained ages suggest a general simplest inverted age profiles, where the first weathered, older assemblage is present at the upper parts of the profile, while more recently oxidized rocks are present in the lower parts of the profile (Fig. 2). Although some samples were displaced by field observed faulting, the broadly horizontal downward migrating weathering front, suggest be related to a general descending water table and deeping of the supergene profile through the Miocene in Northern Chile.

Ages in this study suggest that supergene minerals formation appears to be associated with discrete events rather than continuous mineral generation. Alunite generation is defined by a minor pulse at ~33 Ma and five more significant periods at 27, 25, 22-23, 16-19, and 14-15 Ma, whereas Mn-oxides occurred at 14, 12, and 9-10 Ma pulses. Discrete generation events appear related to tectonic pulses that produces surface uplift by local crustal shortening or by regional tilting. Tectonic activity for these periods has been documented (e.g. Sébrier et al., 1988; McKee and Noble, 1989) and is consistent with supergene mineral precipitation events. Surface uplift provides erosion and downward movement of water table favouring supergene minerals precipitation and pedimentation process. The end of main period of regional pedimentation in Northern Chile (9 Ma) occurred at same time of supergene minerals cease. The moderate precipitation inferred for supergene mineral generation in Atacama Desert suggest a prevalence of semi-arid conditions at least until 9 Ma, or exceptional climatic disturbances that permit humidity transfer across the Andes from Amazons basin into an hyperarid Atacama region (Zachos et al, 2001). The combination of both sporadic wetter periods and surface uplift/erosion, may have controlled the generation of Miocene supergene alunite and Mn-oxides in the Atacama Desert of Northern Chile.

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References

Arancibia, G., Matthews, J., Pérez de Arce, C. K-Ar and $^{40}Ar/^{39}Ar$ geochonology of supergene processes in Atacama Desert, Northern Chile: Tectonic and climatic relations. *Journal of the Geological Society, London, in revision.*

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

Clark, A., Tosdal, R., Farar, E., Plazolles, A. 1990. Geomorphologic environment and age of supergene enrichment of the Cuajone, Quellaveco, and Toquepala Porphyry Copper Deposits, Southeastern Peru. *Economic Geology*, **85**, 1604-1628.

Bissig, T., Clark, A., Lee, J., Hodgson, J. 2002. Miocene landscape evolution and geomorphologic controls on epithermal processes in the El Indio-Pascua Au-Ag-Cu belt, Chile and Argentina. *Economic Geology*, **97**, 971-996.

Bouzari, F. and Clark, A. 2002. Anatomy, evolution, and metallogenic significance of the supergene orebody of the Cerro Colorado porphyry copper deposit, I Regiőn, Northern Chile. *Economic Geology*, **97**, 1701-1740.

Cornejo, P., Mpodozis, C., Matthews, S. 1999. Geología y evolución magmática del distrito Indio Muerto y yacimiento El Salvador. Servicio Nacional de Geología y Minería (Chile), unpublished report IR-98-14, 99 p.

Hartley, A., and Chong, G. 2002. Late Pliocene age from the Atacama Desert: Implications for the desertification of western South America. *Geology*, **30**, 43-46.

Hautmann, S. and Lippolt, H. 2000. $^{40}Ar/^{39}Ar$ dating of central European K-Mn oxides – a chronological framework of supergene alteration processes during the Neogene. *Chemical Geology*, **170**, 37-80.

McKee, E., and Noble, D. 1989. Cenozoic tectonics events, magmatic pulses and base and precious –metal mineralization in the Central Andes. In: Ericksen, G.E., Cañas Pinochet, M.T., and Reinemund, J. A., editors, *Geology of the Andes and its relation to hydrocarbon and mineral resources*: Houston, Texas, Circum-pacific Council for Energy and Mineral Resources Earth Science Series, **11**, 189-194.

Mortimer, C. 1980.Drainage evolution of the Atacama Desert of northernmost Chile. *Revista Geológica de Chile*, **11**, 3-28.

Sillitoe, R. And McKee, E. 1996. Age of supergene oxidation and enrichment in the Chilean Porphyry Copper Province. *Economic Geology*, **21**, 164-179.

Sébrier, M., Lavenu, A., Fornari, M., Soulas, J.P. 1988. Tectonics and uplift in Central Andes (Peru, Bolivia and northern Chile) from Eocene to present. *Géodynamique*, **3**, 85-106.

Vasconcelos, P. M. 1999. K-Ar and $^{40}Ar/^{39}Ar$ geochronology of weathering processes. *Annual Reviews Earth Planetary Science*, **27**, 183-229.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., Billups, K. 2001. Review: Trends, rhythms, and aberrations in global climate 65 Ma to Present. *Science*, **292**, 686-693.