# The uplift history of the western Andes, north Chile, constrained by cosmogenic $^{3}$He in alluvial boulders.

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Accurate timing of uplift of the Andes is essential for understanding continental tectonics processes. Current models vary from gradual uplift of the Andes from the Late Eocene due to crustal shortening/thickening [1] to rapid uplift in the Late Miocene due to large-scale mantle delamination [2]. Existing paleoelevation proxies are afflicted by either large uncertainties or reliance on assumptions about past climate-elevation histories [1]. The production rate of *in situ* cosmogenic isotopes is strongly dependent on elevation and thus has potential to constrain surface uplift histories.

The arid climate in the Atacama Desert, Northern Chile has prevailed since at least 25 Ma [3] leading to low erosion rates and high cosmogenic nuclide concentrations within alluvial boulders overlying the Pacific Planation Surface (PPS). The PPS in the Aroma Quebrada formed at < 13.9 Ma. Alluvial boulders which lie on the PPS, have high concentrations of cosmogenic $^{3}$He that suggest deposition soon after surface formation [4]. The concentration of cosmogenic $^{3}$He in the boulders are compared to those calculated for Early Miocene and Late Miocene uplift histories. The high concentration of cosmogenic $^{3}$He in five boulders cannot be generated by Late Miocene uplift of the Andes (irrespective of scaling factor-production rate). The data require early uplift of the paleosurface prior to 8 Ma. This rules out rapid uplift of the Andes due to mantle delamination in the Late Miocene instead supporting progressive shortening and thickening of continental crust initiating in the Early Miocene or earlier.

[1] Barnes and Ehler (2009) *Earth-Science reviews* **97**, 105-132. [2] Garzione *et al*. (2008b) *Science* **320**, 1304-1307. [3] Dunai *et al*. (2005) *Geology* **33**, 321-324. [4] Evenstar *et al*. (2009) *Geology* **37**, 27-30.

# Nuclear materials under extreme conditions

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During the past forty years, the materials science of nuclear waste forms has focused mainly on the stability and long-term behavior of nuclear waste glasses and the $UO_2$ in used nuclear fuel. However, during this time, substantial quantities of Pu, now more than 2,000 metric tonnes, have been produced. Some 200 mettric tonnes of Pu have been separated along with much lesser amounts of "minor" actinides (Np, Am and Cm). The *nuclear solution* is to prepare a mixed-oxide (MOX) fuel of Pu and U or an inert matrix fuel (IMF) to fission transuranium elements in a reactor. The *geologic solution* is to develop very durable materials for disposal in a geologic repository or a very deep borehold. However, radiation damage in the reactor or self-radiation damage due to the alpha-decay of actinides is a concern, as radiation-induced transformations of the atomic structure decrease the chemical durability.

A variety of materials, with mineral analogues, including oxides, silicates and phosphates, have been investigated because they have a high capacity to incorporate actinides, are chemically durable, and in some cases, are resistant to radiation damage. There has been substantial interest in isometric pyrochlore, $A_2B_2O_7$ (A = rare earths, actinides; B = Ti, Zr, Sn, Hf), for the immobilization of transuranium elements. Four radiation-induced transformations may occur: i) periodic-aperiodic, ii) order-disorder, iii) crystalline-to-crystalline, and iv) chemical decomposition. Certain pyrochlore compositions (B = Zr, Hf) remain crystalline to very high doses of alpha-recoil damage, which is mainly caused by ballistic interactions with the alpha-recoil nucleus.

Most recently, the radiation response of pyrochlore has been investigated using relativistic heavy ions for which high energy deposition occurs by electronic excitation. Energetic ions deposit exceptional amounts of kinetic energy (GeV) within an exceedingly short time (less that a femtosecond) into nano-scale volumes. Energy deposition is up to tens of eV/atom, foming damage tracks, very similar to fission tracks in zircon and apatite. These irradiations have been done at high pressures (>50 Gpa) and temperatures (up to 500 °C) within a diamond avil cell (DAC). The combined use of advanced *in situ* (synchrotron X-ray diffraction and Raman spectroscopy) and *ex situ* (transmission electron microscopy) characterization techniques has shown that normal phase relations are changed by the radiation and that most materials can be amorphized.

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