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Olivines from Archean Komatiites

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Olivines from komatiites represent some of the best available mineral detectors for neutrino and dark matter searches. Komatiites are Mg-rich lavas that are almost exclusive to the Archean (>2.5 billion years old) time period of Earth's history. The high MgO contents of these lavas (typically 25 wt% MgO (Arndt, 2023), cf., 10 wt% MgO for modern basalts) reveal that their eruption temperatures were much higher than what is observed today for basalts erupted at mid-ocean ridges and places like Hawaii.

Nisbet et al. (1987) was the first paper to report melt inclusions (10-50 micron diameter) in fresh olivines from 2.7 billion-year-old Belingwe komatiites in Zimbabwe. This amazing discovery revealed that these lavas are incredibly well preserved. Following this discovery, McDonough and Ireland (1993) reported ionprobe trace element data for these melt inclusions documenting that fluid mobile elements (e.g., K, Sr, and Ba) were still present in their original relative abundances. These data also provided the opportunity to constrain the tectonic environment for komatiite genesis. Since then, other locations of unaltered komatiites hosting olivine-bearing melt inclusions have been identified (Sobolev et al., 2016; Asafov et al., 2018), including locations that are up to 3.3 billion years old (Sobolev et al., 2019).

An unknown in the history of these komatiites is the depth for which they have remained during their multibillion-year residence in the continental crust. We have quantitative constraints (± ~1% uncertainties from radiometric ages) on the eruption and emplacement ages of these lavas. Currently, we do not have quantitative constraints on the depth of burial versus time. Their freshness tells us that these lavas were not at the surface where there is abundant water, which drives almost all alteration processes. That these rocks are >2.5 billion years old and still fresh means that they have been held in some "special place"for a long time to preserve them. A standard crustal geotherm is typically between 10°C and 20°C/km. Therefore, the maximum temperature should only be about 100°C at 5 km depth. This condition is usually not enough to anneal tracks, but might alter these minerals. However, their preservation tells us that the system has been relatively dry over their history and does not have active alteration processes.

There is no quantitative constraint on the history of crustal depth of these lavas; however, reconstruction of the average depth of burial may be possible with strict constraints on their age, location, and U-Th concentrations. The muon flux and, correspondingly, the differential cosmogenic neutron flux, vary as a function of depth and composition of the rock overburden (Fedynitch et al., 2022; Woodley et al., 2024; Marino et al., 2007; Mei and Hime, 2005). The relative shape of the induced recoil spectrum is expected to remain constant with depth, varying only in amplitude. This spectrum can be fitted - and thus the average depth or cosmogenic signal 'reconstructed'- with experimental data and simulation. When using these ancient minerals to detect atmospheric neutrinos, the sensitivity of the required paleo-detector is much less influenced by depth. Tracks induced by nuclear recoils from atmospheric neutrinos can be up to a millimeter in length, exceeding track lengths caused by cosmogenic neutrons. Komatiitic olivines from ages ancient to recent (3300 to 90 million years ago) provide the best possible exposure and purity for atmospheric neutrino detection, allowing us to map changes in the cosmic ray rate throughout Earth's history.

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Yes

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