Olivines in Martian meteorite NWA 104516: alteration and oxygen isotope evolution

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Introduction: Olivines in the Martian meteorite NWA 10416, an olivine-phyric basalt, show signs of hydrous alterations. This iddingsite formation is attributed to pre-terrestrial processes. Generally speaking, iddingsite is a mixture of remnant olivine, clay minerals, iron oxides and ferrihydrite. Studying these altered zones will permit a better understanding of types and extent of hydrous alteration processes at or near Mars' surface.

Alterations: NWA 10416 contains large (1-2 mm) olivine phenocrysts that display iddingsite alterations visible in hand specimens. We identified several zones of alteration, i.e., iddingsite: orange staining in core center ('orange iddingsite'; SiO_2=37, FeO=25, MgO=36, H_2O=6 wt.%), intermingled with dull areas ('weathered orange iddingsite'; SiO_2=15, FeO=47, MgO=5), and brown core margins ('brown iddingsite'; Fo_{49-60} low totals, H_2O=2 wt.%). Clear olivine (Fo_{52-58}) overgrows altered cores with a serrated boundary (Fig. 1) (see also [1,2]). Clear olivine (Fo_{46-53}) is also present in the groundmass. We speculated [1] that the alteration is pre-terrestrial, predating groundmass crystallization.

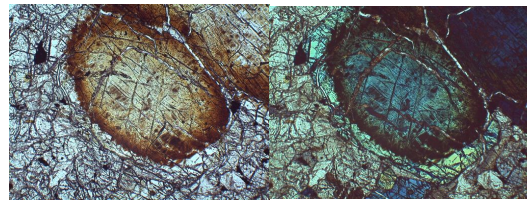
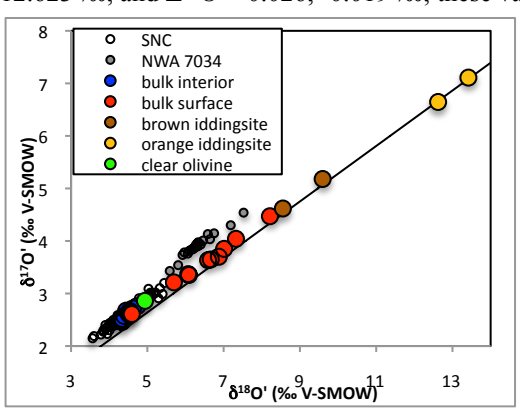


Fig. 1: L: Orange iddingsite (with dull weathered areas) core with brown iddingsite margin, overgrown by a clear olivine rim (PPL). R: XPL image better displays the clear rim.

Oxygen isotope data: Acid-washed bulk rock material from the interior of the stone has a Martian isotope signature: $\delta^{18}O$ = 4.310-4.740 (±0.02) ‰ and $\Delta^{17}O$ values of 0.168-0.327 (±0.02) ‰. Material from the exterior surface of the meteorite has a wider range of $\delta^{18}O$ (4.592-8.214 ‰) and smaller $\Delta^{17}O$ values (0.071-0.205 ‰) (Fig. 2).

Clear olivine, brown iddingsite, and the mixed orange and weathered orange iddingsite were handpicked from gently crushed rock. This material was not acid-treated and not pre-fluorinated in order to not destroy the fragile minerals. The clear olivine oxygen isotope values ($\delta^{18}O$ = 4.937 ‰, and $\Delta^{17}O$ = 0.253 ‰) coincide with those from the bulk interior analyses and are Martian (SNC). The brown iddingsite margin of the altered olivine cores have $\delta^{18}O$ = 8.553, 9.596 ‰, and $\Delta^{17}O$ = 0.102, 0.113 ‰. Similar to the bulk material from the exterior surface, these results from the brown iddingsite extend to a much larger range of $\delta^{18}O$, however, the $\Delta^{17}O$ values are still distinctly non-terrestrial. The orange, heavily altered iddingsite from the centers of the olivine cores yield $\delta^{18}O$ = 13.417, 12.623 ‰, and $\Delta^{17}O$ = 0.026, -0.019 ‰; these values indicate that a terrestrial origin is most likely (Figs. 2, 3)



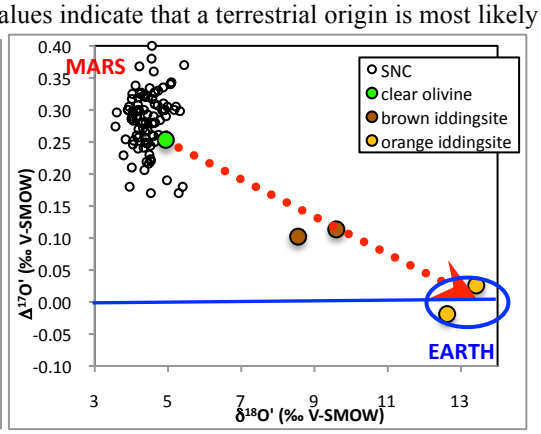


Fig. 2 (left): 3-oxygen isotope plot of bulk rock and separates.
Fig. 3 (right): $\Delta^{17}O$ vs. $\delta^{18}O$ of clear olivine, brown and orange iddingsite: Mars-to-Earth tranistion.

Discussion: The fact that iddingsite is overgrown by clear olivine with typical Martian (SNC) $\delta^{18}O$ and $\Delta^{17}O$ values dictates that the initial alteration of the olivine cores is Martian. Further, iddingsite does not cut terrestrial calcite fractures, and thus is believed to be of hydrothermal origin; this could have only occurred on Mars.

Gradually increasing $\delta^{18}O$ values and decreasing $\Delta^{17}O$ values of the increasingly more altered (brown, then orange) iddingsite towards the core centers indicates subsequent overprinting by terrestrial alteration. Any second stage (terrestrial) alteration would attack and affect the most altered material first; this is demonstrated by the terrestrial $\delta^{18}O$ and $\Delta^{17}O$ values of the orange iddingsite. The less altered material of the brown iddingsite has oxygen isotope values indicating a partial terrestrial overprint onto its original Martian isotope signature (Fig. 3).

These data support our earlier hypothesis [1] that the olivine cores were liberated from their cognate basaltic matrix, altered at or near the surface of Mars, and subsequently incorporated into the basalt that now is NWA 10416.

References: [1] Herd C. D. K. et al. 2016. Abstract #2527. 47th Lunar & Planetary Science Conference. [2] Vaci Z. et al., 2016. Abstract #2538. 47th Lunar and Planetary Science Conference.