HYDROTHERMAL ALTERATION OF 2.7 GA BASALTIC ANDESITES AND IMPLICATIONS FOR PAST FLUID-ROCK INTERACTIONS ON MARS

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Introduction: A ca. 2701 Ma outcrop [1] of greenschist-facies metabasites in the Blake River Group of the Abitibi greenstone belt provides an analogue for studying early Earth and Martian-like hydrothermal fluid interactions with mafic lavas. The Hurd outcrop is located in the central part of the Blake River Block, which shows little evidence of regional deformation or metamorphic overprinting of seafloor hydrothermal alteration [2]. Variably altered samples collected from a section of alternating hyaloclastite and massive flows were investigated petrographically and for their major and trace element geochemistry and O and N isotope compositions. The hyaloclastites, which are believed to have formed during subaqueous eruptions of slightly more viscous magma at the ends of volcanic cycles, show the greatest alteration when compared to massive units and preserve evidence of purported endolithic microorganisms that may have colonized the glasses shortly after their formation [3].

Volcanic Protolith: The samples studied here, from the Hurd Property near Harker Township, Ontario, likely were oceanic plateau basaltic andesites, based on their major and trace element compositions. For these samples, elevated concentrations of HFSE (Y, Ta, Nb, Hf, Zr, and Ti), relative to concentrations in N-MORB, can be explained by increasing differentiation from compositions of more MORB-like samples at a second Blake River Group outcrop in Rouyn, Quebec. HFSE concentrations in least- to moderately-altered Hurd samples are within 20% of their respective mean values. Also, REE patterns of the basaltic andesites are very similar to that of N-MORB but with uniformly elevated concentrations. Relative to Rouyn samples, concentrations of the transition metals V, Ni, and Cr in the Hurd samples are lower by an order of magnitude or more, and Mg and Ca are also lower, consistent with differentiation of a basaltic melt. However, in even the least-altered samples, the degree of major element alteration associated with post-differentiation hydrothermal Si-enrichment remains uncertain. The absence of pillow morphology flows at the outcrop could reflect the higher Si content of the protolith, relative to MORB.

Alteration evidence: Because, for most samples, the enrichment/depletion trends of major elements are obscured by Si enrichment, the following approaches were taken to evaluate extents of hydrothermal alteration and metamorphism.

Secondary mineralogy. Transmitted light optical petrography and bulk powder XRD analysis reveal a classic greenschist-facies alteration assemblage of quartz, albite, and chlorite, with subsidiary calcite, magnetite and actinolite, and traces of other secondary minerals including titanite, illite, and epidote occurring in mostly the hyaloclastite samples. The presence of titanite in several of these samples can be related to the presence of mineralized microbial ichnofossils, which are suspected to occur in three hyaloclastite samples whose previously glassy shards contain characteristic tubular, and some granular, structures. Preservation of microbial ichnofossils by titanite mineralization has been reported from numerous greenstone belt localities worldwide [e.g., 4-5]. Illite is identified by XRD in only four hyaloclastite samples and is suspected to be a result of the sericitization of albite, which itself is largely a secondary alteration mineral after primary igneous plagioclase. It is possible that illite occurs in other samples but at very small modal abundances difficult to identify in thin section and undetectable above the background in XRD. The possibility that illite does not occur in any other Hurd samples is significant because the illite-bearing hyaloclastite samples are four of the six most altered hyaloclastites, suggesting that alteration of select areas was pervasive enough (in duration or fluid temperature evolution) to transition from albitionization to sericitization.

Fluid-mobile elements: The more porous hyaloclastite units appear to have experienced greater extents of alteration with co-enrichment of relatively fluid-mobile elements such as LILE (e.g., K, Rb, Ba, Cs), U, Th, B, and Li. Six samples identified as the most altered are hyaloclastites with the highest contents of fluid-mobile elements and most extensive shard fracturing, and the latter would have increased paleo-porosity and fluid accessibility. Hyaloclastites can be split into two groups: Type I, containing solely brecciated-glass textures, and Type II, containing larger clasts of holocrystalline material.

Metasomatic enrichments of U, Th, B, and Li are significant only in type I samples, representing the alteration of fresh glass by cool to moderate-T seawater-derived fluids. A second phase of alteration involving hotter hydrothermal fluids (T < 220°C based
on $\delta^{18}$O, most likely associated with later-stage volcanism, is represented by the LILE contents, which are enriched in type I and particularly II samples. Abundances of K, Ba, Rb, and Cs in type II samples are consistent with a greater abundance of albite, in holocrystalline clasts, that could be sericitized in the second alteration phase. A third alteration phase can be inferred from a highly silicified zone in the thickest hyaloclastite directly beneath a suspected shallow, intrusive body, whose heat would have enhanced silicification at the boundary with cool host rocks.

The N contents and $\delta^{15}$N of the samples show a very weak anti-correlation, which breaks down especially in an area where putative ichnofossils are preserved and there is greater N content ($\sim 12$ ppm) with, in one case, increased $\delta^{15}$N$_{air}$ ($\sim +6\%$). In general, the N contents at the Hurd outcrop are low (2-8 ppm). These low concentrations are expected as there are few mineral phases where N (as NH$_4^+$) can reside (e.g., feldspars, illite). For hyaloclastites, weakly correlated N and K concentrations indicate the involvement of a N-bearing fluid during the alteration producing secondary clays. Two of the three samples containing putative ichnofossils (but little or no illite) are enriched in N (12 ppm) relative to concentrations of 4-5 ppm expected based on their K contents. Direct association of biologic remnants in the tube wall interiors with anomalously high N contents is tentative at best. For whole-rock basalt and volcanic glass samples from Earth’s modern seafloor, enrichments in N and positive shifts in $\delta^{15}$N from likely protolith values, probably reflect fluid-mediated additions of sediment-derived organic N [6].

Martian analogue: The Martian crust is largely of basaltic composition [7-9]. Numerous lines of evidence suggest the presence of surface water early in Martian history [10-13]. The potential for Martian microbial habitats, based on water-basalt interaction similar to that inferred from terrestrial basalts throughout Earth’s geological record, makes the variably altered, subaqueous basalts on Mars high-value astrobiology targets [14]. The preservation potential of biomarkers in subaqueous-emplaced basalts, such as those described here, should be considered in direct investigations of Martian samples (i.e., meteorites and future sample returns) and by remote sensing and robotic exploration missions.