

TRACE ELEMENTAL COMPOSITION OF ALTERATION MINERALS IN NAKHLITES – SOURCE AND NATURE OF AQUEOUS FLUIDS

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Introduction: Nakhrites are a suite of 20 martian meteorites that crystallized as comagmatic rocks at ~1.3 Ga [1]. Considering that they represent what is considered to be a cold, dry period of Mars' history (Amazonian), they contain relatively abundant (>1 vol%) aqueous alteration minerals: phyllosilicates, carbonates, sulfates and halides containing clues to fluid activities within the martian crust. Models explaining aqueous alteration include contamination of magma by evaporates and sediments [2] and hydrothermal alteration in response to impact-induced melting of sub-surface ice [3, 4]. The post-impact hydrothermal alteration model is the most widely accepted scenario, due to the fact that it easily accounts for the age of phyllosilicate formation, constrained at ~680 Ma by Rb-Sr and K-Ar dating [5]. However, this model struggles to explain the large compositional and textural variation within observed alteration assemblages across the whole nakhlite suite [6] and further analysis of the alteration geochemistry and mineral textures is needed to distinguish between existing ideas or develop new models.

Aims and methods: We analysed the trace elemental compositions of the alteration products in two nakhlites: Nakhla and Lafayette. Several non-treated chips from the two meteorites were characterized by correlated SEM-EDX major element composition analysis and synchrotron-based XRF minor and trace element mapping. Alteration mineral assemblages were identified in exposed surface, their location in relation to primary minerals as well as their textures described, and composition qualitatively measured. Elemental maps were collected from areas as large as 500 µm x 500 µm in each meteorite fragment allowing for comparisons of trace elemental budgets of various alteration phases within the assemblages to be made. The XRF beam energies were adjusted to specifically target elements such as: REE, Ba, Rb, Sr, Zr, Zn, Cu, Ni, Br. These elements were chosen as they have the potential to yield information regarding the sources of fluids.

Results: In Nakhla, alteration mineral assemblages are mainly located in veins within olivine crystals. Our maps were collected from exposed surfaces of split alteration veins. In such locations, Fe,Mg-phyllosilicates and Fe,Mg-carbonates dominate the alteration products. Mn-rich carbonates are present close to edges of olivine grains, at contacts with augite or mesostasis. We observe significant differences in trace elemental compositions of the two groupings of carbonates. Fe,Mg-carbonates do not host any of the targeted elements, while Mn-carbonates reveal the presence of Ca, Cu, Zn, Ni, minor La and Ce. Additionally, clear signals from Cl and Br are detected in association with Mn-rich carbonates. Fe,Mg-phyllosilicates in Nakhla contain K, Rb, Cl and some Br. Sulfates in Nakhla, most likely gypsum, are present along cracks that pervade both olivine and augite. They contain Sr and Ba and sometimes Sr zonation is seen in the grains. In Lafayette, alteration minerals predominantly occur in olivine and are represented by Fe,Mg-phyllosilicates and carbonates. In contrast to Nakhla, only one generation of carbonates is observed, containing Fe, Ca and some Mn. Of the trace elements, only Sr and Ba are detectable. Unlike in Nakhla, no Cl or Br are seen in association with carbonates. Phyllosilicates in Lafayette host K and Rb but no Cl or Br is detected.

Discussion: Trace elemental composition of alteration minerals in Nakhla and Lafayette reveal a complex aqueous system in the martian subsurface. A single evaporation event of CO₂-charged fluid [3] cannot explain the multiple crystal chemical assemblages. Distribution of Cl and Br between various alteration minerals and differences in trace elemental composition of two generations of carbonates in Nakhla require further discussion. These features may suggest that: (i) alteration may have occurred in a low fluid:rock environment, where dissolution plays a significant role and the trace elemental budget is strongly influenced by locally dissolved phases, (ii) more than one episode of fluid activity altered the nakhlites in the subsurface, and specifically, Fe,Mg-carbonates formed separately from Mn-rich carbonates in Nakhla, (iii) the altering brine was originally rich in Cl, which affected fractionation of trace elements during fluid percolation and evolution. When considering the impact-triggered hydrothermal cell model [3, 4], the source of Cl in the brine needs to be defined. Alternatively, the Cl content of the fluid may point towards at least some of alteration products in nakhlites forming during the late magmatic stage of evolution, when Cl-rich fluid infiltrated the nakhlite magma chamber [7, 8].

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