

METAMORPHISM ON MARS: A VIEW FROM ESKOLAITE-BEARING CHROMITE-MAGNETITES IN NWA 7533. Yang Liu¹, Chi Ma², John Beckett², David Flannery¹, Abigail Allwood¹. ¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA. ²Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA. (Email: yang.liu@jpl.nasa.gov).

Introduction: Eskolaite (Cr_2O_3) is a rare mineral on Earth, first discovered in metal-sulfide deposits and skarns in the Outokumpu mine in Finland [1], and then reported in other ore deposits or with greywacke/alluvium (see [2-3]). Eskolaite has also been found in high-pressure rocks [4-6].

In extraterrestrial materials, eskolaite, most of which are sub- μm to μm sized grains, are known from the lunar regolith, ureilites, carbonaceous chondrites, and in the fusion crusts of iron meteorites [7-14]. The only reported occurrence in a Martian meteorite is as ~ 10 nm grains, coating silica glass in ALHA 84001, which was attributed to condensation following vaporization of chromite in an impact [15].

In our study of the ‘Black Beauty’ meteorite NWA 7533 using a breadboard model of PIXL, the X-ray fluorescence spectrometer selected for Mars 2020 rover, we detected high-Cr phases. Most of these are chromites, but one grain contains eskolaite. Further investigation of another NWA 7533 section and one NWA 7034 using EPMA X-ray mapping and SEM yielded one more eskolaite crystal enclosed in chromite in NWA 7533. Here we report the texture and mineral association of the eskolaite-bearing grains, preliminary compositions from SEM-EDS analysis, and consider possible formation mechanisms on Mars.

Results: The eskolaite (Esk) grain encased in chromite (Chr)-magnetite (Mag) was observed in each of the two sections of NWA 7533 (Figs. 1 and 2). EBSD analysis confirmed the corundum structure of both grains. The eskolaite grains are single crystals ~ 30 - $90 \mu\text{m}$ long and ~ 10 - $20 \mu\text{m}$ in the smallest dimension. Both grains are embayed by the mantling chromite, which is further rimmed by aggregates of magnetite, augite (Aug), pigeonite (Pgt), and plagioclase (Pl) with a minor amount of chlorapatite (Cl-Ap) and ilmenite. One of the occurrences also contains merrillite (Mer)-chlorapatite (Fig. 1), which contacts with eskolaite are separated by a thin selvage of chromite.

The eskolaite grains are relatively uniform in composition, except for Fe_2O_3 (e.g., 0.9-1.4 wt% in the grain in Fig. 1). V_2O_3 concentrations are ~ 0.35 wt% (Fig. 1) and 1.29 wt% (Fig. 2), respectively. Both grains contain 96-98 wt% Cr_2O_3 , <0.5 % Na_2O , <0.5 % SiO_2 , <0.1 % MgO , and <0.1 % Al_2O_3 . These compositions correspond to a formula of $\text{Esk}_{98}\text{Hem}_1\text{Kar}_1$ (Fig. 1) and $\text{Esk}_{97}\text{Hem}_1\text{Kar}_2$ (Fig. 2), where Hem refers to the hematite (Fe_2O_3) component and Kar to the karelianite (V_2O_3) component. Terrestrial examples are

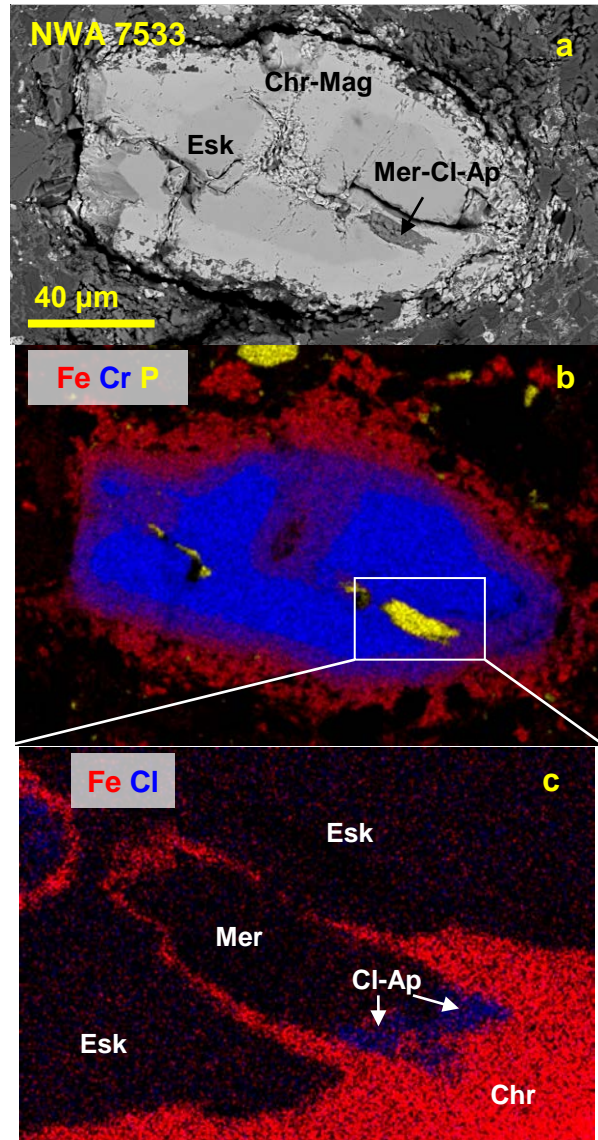


Figure 1. Back-scattered electron (BSE) image (a) and X-ray maps (b, c) of eskolaite enclosed in chromite-magnetite in NWA 7533.

higher in one or more cations of Al, V, Ti and Fe [1, 3-5]. The mantling chromite-magnetite is polycrystalline based on preliminary EBSD and shows compositional zonation from nearly pure chromite in contact with eskolaite to Cr-magnetite (Fig. 4). The magnetite mixed with silicates in the rim varies from Cr-bearing magnetite to nearly pure magnetite (Fig. 4). Mg# of the chromite-magnetite varies from 4-16.

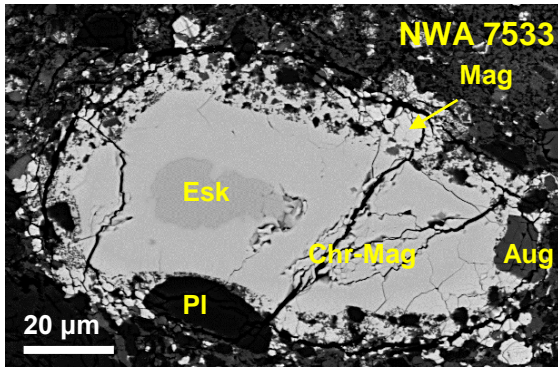


Figure 2. BSE image of a second eskolaite (Esk) grain in NWA 7533.

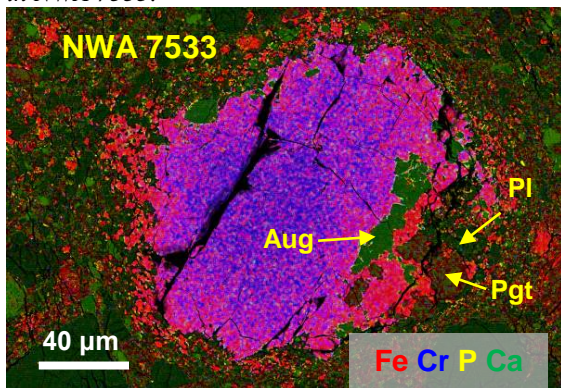


Figure 3. Composite X-ray maps of an eskolaite-free chromite-magnetite grain in NWA 7533.

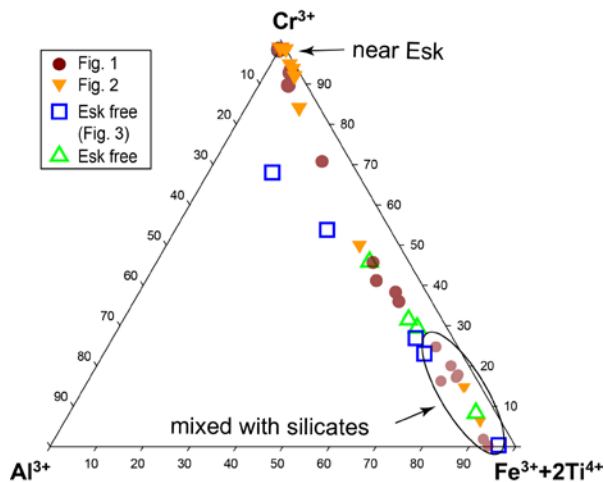


Figure 4. Composition of chromite-magnetite in terms of octahedral site occupancy.

Most chromite-magnetite assemblages in our samples of NWA 7533 are eskolaite-free (e.g., **Fig. 3**); these grains also display increasing Fe and decreasing Cr from center-to-rim (**Fig. 4**) and are often bound by similar a rim of similar phase assemblage.

Discussion: Eskolaite has never been reported as a primary igneous phase, and this reflects the enhanced stability of chromite-magnetite and other Cr-phases relative to sesquioxides in magmatic environments.

Eskolaite in most natural samples are secondary in nature. Eskolaite in ureilites are formed by high-T reduction of primary chromite through shock metamorphism [14], but we see no evidence for reduction agents (e.g., metals/carbides/graphite) in NWA 7533 that might facilitate such reactions. Moreover, eskolaite in NEW 7533 is texturally earlier than the enclosing chromite-magnetite, not a product of it. However, the formation of terrestrial eskolaite often involves fluids in metamorphic rocks (e.g., [3, 16-18]), or in metasomatized mantle rocks [4, 5].

The anhedral shape of eskolaite and the zoned mantle of increasing Fe^{3+} contents toward the rim suggest that eskolaite reacted with or was replaced by an oxidizing fluid. In low temperature aqueous fluids, Cr^{3+} is generally thought to be essentially insoluble except in contact with Mn oxides [e.g., 19]. At elevated temperatures in alkali-, Cl-enriched fluids, however, Cr^{3+} becomes soluble [20-21] and, therefore, mobile. As the temperature or fluid composition is changed, either eskolaite or chromite may become the stable Cr-bearing oxide.

Summary: The unusual associate of eskolaite and chromite-magnetite in NWA 7533 suggests an active hydrothermal environment in the martian crust. In our previous studies of NWA 7034/7533, we suggested that REE-phosphates and REE-silicate reflect hydrothermal events in the martian crust [23-24]. Reaction of eskolaite to chromite-magnetite provides additional constraints on the nature of hydrothermal processing of the Martian crust.

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