INCLUSIONS IN EXTRATERRESTRIAL CHROME-SPINEL FROM JURASSIC SEDIMENTS

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Introduction: Meteorites provide insights into solar system processes, but they quickly weather away once they reach Earth's surface. Fortunately, remnant extraterrestrial chrome-spinels resist weathering. These preserved grains can be found in limestone throughout the sedimentary record and originate from meteorites or micrometeorites. The overall objective of studying remnant chrome-spinels is to understand how meteorite populations have changed over time. The parent meteorite type of chrome-spinels can be classified based on the elemental and oxygen-isotope abundances of the grain and on the inclusions found in some chrome-spinels [1]. Recent studies [2-3] have shown that olivine (fayalite content, Fa) and low-Ca pyroxene (ferrosilite content, Fs) compositions can help distinguish between overlapping meteorite types, such as L- and LL-chondrites. The objective of this work is to accurately classify extraterrestrial grains from the Jurassic time period [4] using transmission electron microscopy (TEM) on focused ion beam (FIB) prepared sections of inclusions.

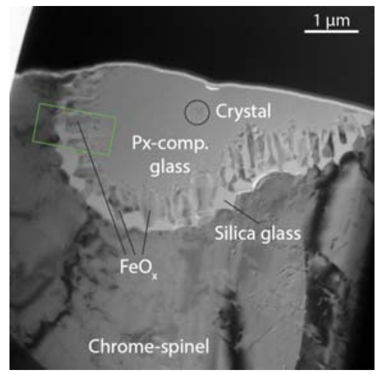

Fig. 1: TEM bright field of inclusion surrounded by chrome-spinel.

Experimental: Chrome-spinels were recovered at Lund University from Spanish limestone; see [1] for methods. The grains were epoxy mounted at the University of Hawai'i (UH) in steel cylinders. The mounts were ground flat and polished using a series of diamond lapping papers. Elemental abundances of inclusions were determined using the UH FEI Helios 660 dual beam FIB-SEM. A TEM sample of the inclusion was prepared by standard FIB methods. We used the UH FEI 80-300 kV Titan dual C_s-corrected and monochromated (scanning) TEM to image and analyze elemental chemistry at 300 kV.

Results and Discussion: The inclusion in this study is shown in Fig. 1. The surrounding chrome-spinel gives a classification of LL chondrites for the parent meteorite based on elemental abundances, but oxygen isotopes indicate an L chondrite [4]. The ambiguity between L- and LL-chondrites has been observed previously and, in some cases, can be resolved based on the minerals in inclusions. The inclusion in Fig. 1 is predominantly pyroxene-composition glass with a rim of iron oxide (FeO_x) and silica glass. The composition of the pyroxene glass is Fs ~38 (mole %), which is more Fe-rich than pyroxene previously observed in chrome-spinel inclusions from ordinary chondrites (Fs ~15-25) [2-3]. This inclusion measures outside of the range of previous studies and cannot be classified using this method.

A similar rim of FeO_x was found by [2] but further analyses were not performed. Figure 2 shows TEM element maps where the arrows are the boundary between the chrome-spinel and the FeO_x and silica rim. From the present data, it is unclear whether the FeO_x (and silica) formed by alteration of existing chromite or by (epitaxial) growth from the inclusion. The high Fe content of the pyroxene-glass and the FeO_x rim suggests that Fe was mobile. This rim may have formed while the chrome-spinels were sitting on the Jurassic sea floor for hundreds of years via oxidized aqueous alteration.

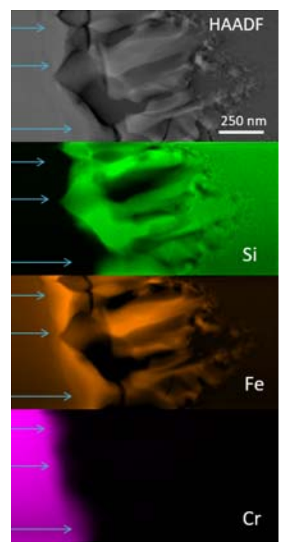

Fig. 2: TEM element maps of area in Fig. 1.

Three other pyroxene inclusions are exposed in this grain, and SEM-EDX spectra show that all have Fs contents similar to the inclusion in Figure 1. A spectrum taken for the inclusion in Fig. 1 prior to FIB section preparation shows a 2% higher Fs content than the TEM spectra. This is likely due to contributions from the surrounding chrome-spinel due to the higher interaction volume of SEM-EDX. TEM-EDX is vital to the understanding of these inclusions based on complexities that cannot be seen in SEM-EDX.

Conclusions: Our study shows that inclusions in chrome-spinel are complex. Terrestrial processes may alter some inclusions, such as the one described here. TEM compositional analysis removed the potential for contributions from the surrounding chrome-spinel and revealed an inclusion dominated by Fe-rich pyroxene glass with a rim of FeO_x and silica glass. Currently, we are preparing additional exposed inclusions for analysis.

References: [1] Schmitz, B. (2013) *Chem. der Erde* 73:117-145. [2] Alwmark C. and Schmitz B. (2009) *GCA* 73:1472–1486. [3] Alwmark C. et al. (2011) *MAPS* 46.8:1071-1081. [4] Caplan C. et al., (2017) *LPSC XLVIII*, Abstract #1690. Supported by NASA grant NNX16AQ08G (GRH).