FUSION CRUSTS ON METEORITES: SIMPLE MELTING OR PETROGENETIC SIGNATURE?

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Introduction: Many meteoritists would agree that the bulk composition of a meteorite can be approximated from an analysis of its fusion crust. Indeed, it seems to have become a common practice to use the average of a few fusion-crust analyses as the bulk composition. However, a few analyses will not adequately represent the significant compositional variation within the fusion crust, let alone the bulk composition of the entire rock. In order to explore this premise, the abundant fusion crust that is preserved on the lunar meteorite Miller Range (MIL) 05 035 (thin sections 6 and 40) were analyzed with an electron microprobe and compared to the published bulk-rock composition [1]. These analyses demonstrate considerable variability from the bulk composition and indicate that the mineral substrate has considerable influence on fusion crust composition.

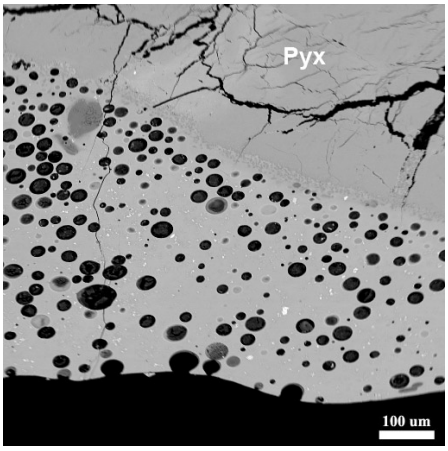

Figure 1. Back-Scattered Electron image of MIL 05 035,40 fusion crust with pyroxene substrate. The fusion crust is unusually thick at this location and contains abundant vesicles. These vesicles have nothing to do with the presence of solar-wind, contrary to that believed as the cause for the vesicularity of fusion crust on lunar regolith breccias.

Methods: Polished thin sections MIL 05 035,40 and 6, were examined with a petrographic microscope in both reflected and transmitted light in order to identify mineral assemblages and their textural relationships. Electron microprobe (EMP) analyses were performed to determine the composition of the fusion crust and adjacent mineral substrate. All analyses were performed with an accelerating potential of 15 keV, 10 nA beam, and a spot size of 5 μm. The average of 141 fusion-crust analyses were then compared to the bulk-rock composition.

Mineralogy and Petrology: Lunar meteorite MIL 05 035 is 142.2g of unbrecciated low-Ti mare basalt which was found during the 2005-2006 Antarctic Search for Meteorites (ANSMET) field season. The meteorite thin sections that were used in this study (6 and 40) are comprised of ~ 66 volume % of coarse pyroxene, and ~ 29% shocked plagioclase feldspar (maskelynite). The remaining ~5% is a combination of: interstitial minerals such as fayalite, troilite, and ulvöspinel, which is intergrown with ilmenite, and tridymite; Fe-rich pyroxene assemblages that include intergrowths of olivine, tridymite, and ferroaugite; and mesostasis composed of K-rich glass, fayalitic olivine, merrillite, baddeleyite and tridymite [2].

The pyroxene crystals that comprise the bulk of these samples are anhedral and very-coarse grained (3 - 8 mm); many of the crystals display twinning and apparent exsolution lamellae. The fractured nature of the pyroxenes and the transformation of the plagioclase crystals into maskelynite is indicative of shock pressure experienced during excavation of this rock from the lunar surface. The plagioclase crystals in this sample are subhedral, up to 1.5 mm long, with compositional zoning that varies from An_{82-94}. Some crystals along the external surface, adjacent to the fusion crust, have been partially recrystallized as fine-grained feathery plagioclase laths. The opaque assemblage is comprised of ilmenite, ulvöspinel, and troilite. Of these, one large ilmenite and one large ulvöspinel crystal comprise the bulk of the opaques in 05 035,40; several smaller crystals of each and many small crystals and blebs of troilite can also be seen throughout these samples. The areas that have a symplectic texture are comprised of small crystals (~5-10 μm) of anhedral SiO_2, fayalite, and pyroxene (Wo_{40} En_9). The fusion crust is highly vesicular and varies in thickness from <0.1 mm to ~0.6 mm along the outer surface of the samples.

Discussion: Sample 05035,40 is unusual in that it has a preserved fusion crust over >75% of the outer surface, and contains an area where this crust is approximately 0.6 mm thick. The abundance of fusion crust provides a rare opportunity to examine the fusion crust composition and its relation to minerals that make up its substrate.

The fusion-crust composition was formed by the melting of the minerals that are exposed at the surface of the meteorite, but the bulk composition is not represented at all points on the surface. The intense heating and melting of the rock's surface as a meteorite passes

through the Earth's atmosphere further modifies the composition as volatile elements can be boiled away producing a fusion crust with numerous vesicles. In order to determine an average composition for the fusion crust, 141 analyses were averaged and compared to the bulk-rock composition (Figure 2). Notice the dispersed nature of the analyses. As can be seen in

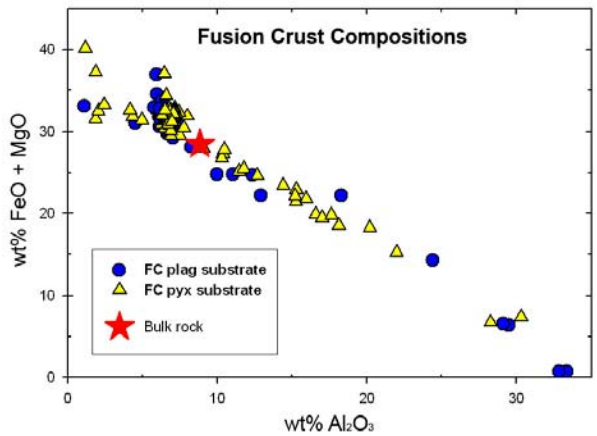

Figure 2. EMP analyses indicating fusion crust compositional variation versus the bulk-rock composition. The cluster of points around 7% Al_2O_3 and 31% FeO + MgO would be expected since pyroxene is the primary mineral component in this sample.

Figure 3, fusion-crust analyses with a plagioclase substrate indicate both a gradual change from a dominantly plagioclase composition to a pyroxene composition, as well as a completely pyroxene-dominated composition. The fusion crust adjacent to a pyroxene substrate seems to vary less and reflects the pyroxene composition (Fig. 4). Compositions of the fusion crust vary with respect to the substrate mineralogy, or reflect the mineralogy around it. This suggests that

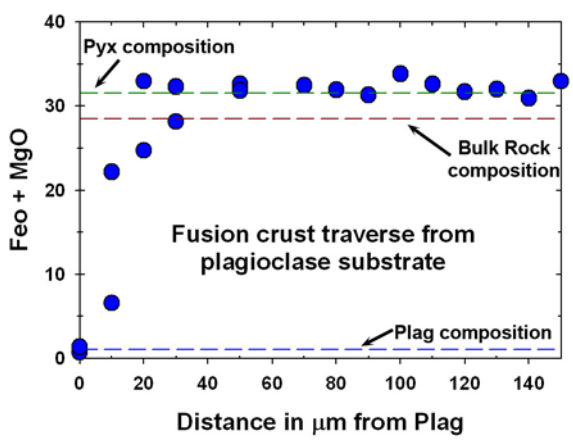

Figure 3. EMP traverse from plagioclase substrate through the adjacent fusion crust. Composition transitions from plagioclase dominated to pyroxene dominated.

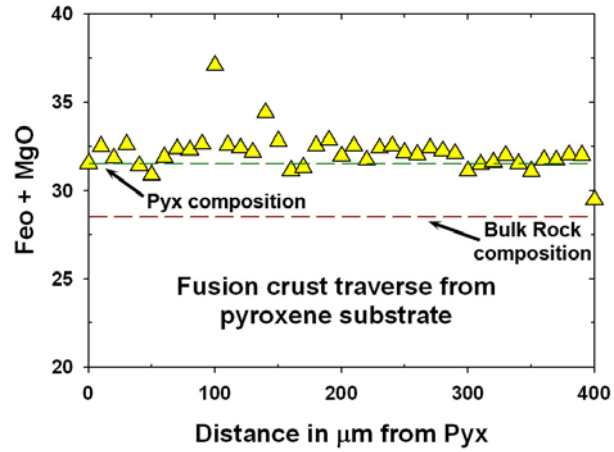

Figure 4. EMP traverse from pyroxene substrate through the adjacent fusion crust. The fusion crust maintains a pyroxene dominated composition.

mixing has occurred but is incapable of homogenizing the fusion crust.

As shown in Figure 5, the average composition of the fusion crust is deficient in Si, Mg, Ca, and Cr, and contains excessive Fe, Ti, Al, Na, Mn, and K, relative to the bulk-rock composition. A highly significant point to be made here has to do with imprecision in the Fe and Mg, as this affects the Mg# of the sample. ***The bulk rock Mg# = 40.1, and the averaged fusion crust has a Mg# = 31.8, which could have major significance on petrogenetic modeling.***

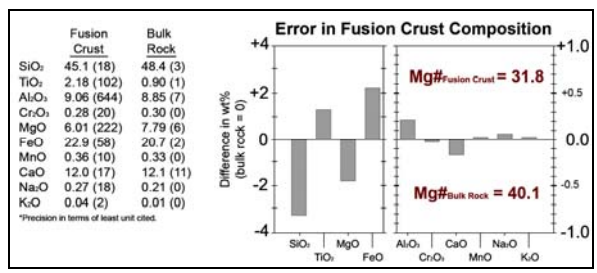

Figure 5. Comparison between the bulk-rock composition [1] and the average of 141 EMP fusion crust analyses.

Summary: Although it has become a generally accepted practice to use the composition of the fusion crust as an estimation of the bulk-rock composition, this procedure seems ill-advised in light of the considerable variation in fusion-crust compositions. The bottom line is that **fusion-crust compositions of meteorites are not those of the bulk rock, and they should always be used with caution.**

References: [1] Joy K.H., Anand M., Crawford I.A. and Russell S. S. (2007) *LPS XXXVIII*, abstract #1867. [2] Liu Y., Hill E., Patchen A., and Taylor L.A. (2007) LPS *XXXVIII*, abstract #2103.