

HIGH TEMPERATURE IGNEOUS SILICATE-SULFIDE ASSEMBLAGES IN COMET SAMPLES

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Introduction: Our continued studies of samples from comet Wild 2 and a giant cluster IDP, which has a likely cometary origin [1], suggest that comets contain silicate-sulfide assemblages which may have igneous origins. These assemblages join other high temperature materials in comets including CAIs, AOAs, ferromagnesian and Al-rich chondrules and Kool grains [1-4]. Consisting primarily of mixtures of pyrrhotite and/or pentlandite with FeO-bearing olivine or low-Ca pyroxene +/-silicate glass, the silicate-sulfide comet samples have mineralogical, chemical and textural properties consistent with formation from high temperature igneous melts. The Fe,Ni sulfides are frequently associated with Kool grains, enigmatic assemblages of **K**osmochloric high-Ca pyroxene+FeO-bearing **oli**vine+albitic feldspar or Na,Al-silicate glass +/-chromite believed to have formed by igneous or thermal metamorphic processes [4], thus Kool grains and the high temperature sulfides appear to be linked.

Techniques/Methods: Relatively coarse-grained (grain sizes up to several μm) silicate+sulfide-rich comet grains were studied by TEM and SEM. The grains were extracted from silica aerogel Stardust tracks (comet Wild 2) or handpicked from a giant cluster IDP (GCP) collected in the stratosphere by a NASA U2 aircraft. A large body of evidence supports a cometary origin for the cluster IDP [1]. For the TEM studies, the samples were microtomed to <70 nm and observed with a Tecnai TF20 STEM equipped with conventional and STEM bright- and dark-field detectors and an EDAX EDX X-ray analysis system.

Results: FeO-rich, low-Ca pyroxenes and/or olivines are the dominant crystalline silicates associated with the sulfides which are principally pyrrhotite +/-pentlandite. Examples of some of the comet silicate-sulfides believed to have originated as high temperature melts include 1) GCP fragment LT28, a mixture of pyrrhotite, $\text{En}_{90}\text{Wo}_3$, albitic feldspar and Na,Cr augite, 2) GCP fragment P6-1, a mixture of Fo_{86} , $\text{En}_{85}\text{Wo}_4$ and pyrrhotite, 3) Wild 2 fragment 'Sitara' composed of $\text{En}_{79-83}\text{Wo}_4$, Na,Cr augite, minor Na,Al silicate glass, pyrrhotite and pentlandite and 4) track 77 fragment 5, an assemblage of Fo_{65-69} , Na,Cr diopside, albite/Na,Al silicate glass and Fe,Ni sulfides. These and numerous other fragments from the comet samples display textures reminiscent of igneous crystallization including sharp grain boundaries and deep embayments between silicates and sulfides. In some of the comet particles, small magnetite grains are present in the interiors of the pyrrhotites and are likely products from O partitioned in the sulfide melts. Small quantities of Ni have been observed in some olivines associated with sulfides indicating partitioning of this element between the olivine and sulfides. No phyllosilicates are observed in any of the silicate-sulfide samples.

Discussion: Pyrrhotite is the most common Fe,Ni sulfide to form during crystallization in terrestrial mafic silicate magmas and forms from immiscible sulfide liquids that are produced during cooling from changes in FeO, SiO_2 , oxygen fugacity, temperature and other parameters. We hypothesize that the silicate-sulfide assemblages in the comet samples crystallized from ~chondritic melts which subsequently lost variable amounts of S during cooling. Because the S abundance is high in chondritic materials, solid chondritic objects which were melted would instantly produce an immiscible sulfide liquid in the silicate melt. Subsequent crystallization would partition Fe (as well as Ni and other chalcophile elements) into the sulfide liquid thus removing some of the Fe from the silicate melt fraction. The amount of Fe remaining in the silicate melt after the formation of the immiscible sulfide liquid would depend on the amount of S retained, thus S in the melt directly influences the final silicate Fe/Mg ratios. MELTS modelling [5] of a chondritic composition melt after sulfide removal shows that Fo_{74} olivine is produced with small amounts of high-Ca pyroxene and Na-rich feldspar (+minor Mg,Al chromite), an assemblage which resembles a Kool grain (MELTS cannot be used to model the kosmochloric component in the clinopyroxene). This suggests that if precursor chondritic materials were melted, compositions of the final crystallization products in both the silicate and sulfide portions, and the mineral assemblages to some degree, would be influenced by the amount of S loss. Because S is a volatile element and large amounts of sulfide are present in the silicate-sulfide samples, it is suggested that both the heating and cooling sequences were rapid thereby retaining some or most of the sulfur.

Conclusions: Mineral compositions, textures, the presence of silicate glass, associations of sulfides with Kool grains and the occurrence of magnetite in some pyrrhotites are suggestive that some silicate-sulfide assemblages formed from ~chondritic composition melts at high temperature. These samples join a list of other high temperature materials found in comets. The sulfide+Kool grain occurrences, grain sizes and the presence of pyrrhotite, rather than troilite, suggests these assemblages are not linked to chondrules. Sulfide saturation and variable S loss would markedly affect the final Fe/Mg and Fe/Ni ratios in the silicates and sulfides. Envisioned scenarios include flash heating/rapid cooling of chondritic dust in either the solar nebula or in plumes from impacts on planetesimals.

References: [1] Joswiak and Brownlee (2017) *MAPS*, in press. [2] Nakamura et al. 2008. *Science* 321:1664-1667. [3] Gainsforth et al. (2015) *MAPS* 50: 976-1004. [4] Joswiak et al. (2009) *MAPS* 44: 1561-1588. [5] Ghiorso and Sack (1995) *Contrib. Min. Petrol.*: 119: 197-212.