POSSIBLE IGNEOUS ORIGINS OF SULFIDE-SILICATE ASSEMBLAGES FOUND IN COMET WILD 2 AND A GIANT CLUSTER IDP OF PROBABLE COMETARY ORIGIN. D. J. Joswiak and D. E. Brownlee, University of Washington, Dept. of Astronomy, Seattle WA 98195 joswiak@astro.washington.edu.

Introduction: Some coarse-grained polymineralic sulfide-silicate assemblages observed in comet Wild 2 and in a giant cluster particle (GCP) have textures and mineral compositions consistent with formation at high temperatures. The sulfides - typically pyrrhotites - appear to be in textural equilibrium with surrounding silicates. Because equilibrium condensation calculations on nebular gas predict the formation of troilite, rather than pyrrhotite, the observed fragments are likely secondary in origin and may have formed from melting of pre-existing solids.

Terrestrially, pyrrhotite often forms during cooling in high-temperature sulfur-bearing magmas co-crystallizing with silicate and oxide phases including olivine, pyroxenes, plagioclase, spinels and silicate glass [1]. Enigmatic Kool grains, assemblages of FeO-bearing olivine, kosmochloric high-Ca pyroxene+/-spinel+/-albite+/-Na,Al silicate glass [2] are found in the sulfide-silicate assemblages. Kool grains may have high temperature igneous origins.

We present mineralogical and textural observations of sulfide+silicate particles and discuss evidence for possible high temperature formation. Additionally, a Ni-rich pyrrhotite+pentlandite fragment is presented that may also have a high temperature origin.

Samples and methods: A subset of relatively coarse-grained (> 1–2 µm) fragments composed of sulide+silicate minerals from comet Wild 2 and a giant cluster IDP were studied by SEM and TEM. We believe that the giant cluster IDP, which has a bulk chondritic elemental composition, is likely to be cometary because it 1) is friable, 2) is unequilibrated, 3) has Fe and Mn contents in olivine similar to Wild 2 [3], 4) is morphologically similar to grains imaged from comet 67P by the Rosetta spacecraft [4], 5) has an abundance of Kool grains which are only found in anhydrous IDPs and Wild 2 [2] and 6) has a Mg# vs Δ^{17}O relationship in ferromagnesian silicates similar to Wild 2 [5].

The Wild 2 and GCP fragments were embedded in acrylic or epoxy resins. Microtome sections < 70 nm thick were cut from potted butts and studied with a 200 keV Tecnai TF20 STEM equipped with an EDAX light element X-ray detector. EDX spectra were quantified using mineral and glass standards with Cliff-Lorimer correction techniques [6]. SEM backscatter electron images of the potted butts were obtained to complement bright-field, dark-field and HAADF images obtained from the TEM. Element maps were collected on some microtome sections to further study mineral relationships or to calculate modes or bulk compositions.

Results: BSE images of five fragments dominated by Fe,Ni sulfide+silicate assemblages and the Ni-rich pyrrhotite+pentlandite fragment are shown in Fig 1. These include (a) GCP LT28: pyrrhotite+$En_{90}Wo_3$+ albitic feldspar+Na,Cr augite, (b) GCP LT34: pyrrhotite+$En_{82}Wo_3$+minor Fo_{90} and Na,Cr augite, (c) GCP P6-1: pyrrhotite+$En_{85}Wo_4$+Fo_{86}, (d) GCP LT27: Ni-rich pyrrhotite+pentlandite, (e) Wild 2 T77 (Puki): Fo_{67}+Na,Cr augite+Fe,Ni sulfides+minor Na,Al silicate glass and (f) Wild 2 T27 (Sitara): $En_{78}Wo_4$+Na,Cr augite+pyrrhotite+pentlandite

Low-Ca pyroxenes are the dominant silicate in fragments LT28, LT34 and T27 (Figs. 1a, b and f) and all have sharp grain boundaries with Fe,Ni sulfides. In LT34 subhedral to euhdral enstatite (+Fo_{90}+Na,Cr-rich augite) is embayed into pyrrhotite, a texture reminiscent of igneous crystallization. Similar textures are observed in fragment P6-1 (Fig. 1c). In this fragment subequal olivine is coexistent with low-Ca pyroxene. Both silicates have similar Fe/(Fe+Mg) ratios suggesting equilibration.

Small Fe oxide grains (< 500 nm), believed to be magnetites, were occasionally observed in the interiors of pyrrhotites in GCP fragments LT28 and LT34. Some pyrrhotites in fragments from the giant cluster IDP have distinct magnetite rims which were produced from oxidation during atmospheric entry but the observed magnetites in the interiors of pyrrhotites in LT28 and LT34 suggest a pre-atmospheric entry origin. Fragment LT27 (Fig. 1d), is composed of Ni-rich pyrrhotite and pentlandite, a texture suggesting that it may have formed from high temperature MSS followed by exsolution at lower temperature.

Discussion: Pyrrhotite is typically the most common high temperature Fe,Ni sulfide in terrestrial magmas [7]. During cooling, a silicate melt may become saturated in sulfur from a decrease in FeO, enrichment in SiO_2 or changes in other parameters thereby promoting separation of sulfide liquid or sulfide crystals from coexisting silicate melt [8]. The textures and mineral assemblage in fragment LT28 are suggestive of a similar process, thus we used [8] to calculate the sulfur content at sulfide saturation (SCSS) using the bulk composition of this fragment. The results indicate that a putative melt of LT28 composition would be sulfur saturated near the liquidus temperature and therefore would likely be composed of immiscible sulfide and silicate liquids. MELTS modelling [9] of the bulk silicate liquid after sulfide removal (fO_2 = IW+2, olivine suppressed), shows that FeO-rich orthopyroxene would be expected to be the dominant crystallizing phase followed by albitic feldspar and high-Ca pyroxene (+ minor amounts of spinel). Although the Fe/(Fe+Mg) ratio of orthopyroxene in the MELTS model is somewhat higher than measured in LT28, this scenario can reasonably account for the observed minerals and textures.

In type I chondrules in the CV3 chondrite Vigarano, Fe sulfides (troilite primarily) and host low-Ca pyroxenes (+/-olivine) were shown to have crystallized at high temperature from coexisting immiscible Fe sulfide and silicate liquids [10]. Within the troilites are small magnetite grains likely resulting from small amounts of oxygen segregating into the immiscible sulfide. Magnetite grains inside pyrrhotites are also observed in terrestrial basaltic magmas [8]. The observed pyrrhotite+magnetite grains in LT28 and LT34 are consistent with formation at high temperature similar to some chondrule melts and terrestrial magmas.

Recently [11] used morphological, petrographic and compositional arguments to suggest that pentlandite (often coexisting with pyrrhotite) in OC, R, CM and CK chondrites was more consistent with high temperature formation than low temperature aqueous alteration. We believe that similar arguments apply to GCP LT27 (Fig. 1d), the pyrrhotite+pentlandite fragment.

Although pyrrhotite and pentlandite in chondrites and IDPs are known to form by aqueous alteration, the evidence for high temperature formation of sulfide-silicate fragments presented here is compelling enough to warrant further investigation as a viable formation mechanism. We note that phyllosilicates are absent in samples from both comet Wild 2 and GCP.

We envision that the sulfide-silicate fragments may have formed from melting of pre-existing materials. Although the formation of sulfur-rich silicate particles at high temperatures may be difficult to reconcile in a nebular setting where volatile sulfur is expected to be lost to the surrounding environment, [12] has shown that in simulated chondrule heating experiments some sulfides survive if heating times are short, cooling rates are fast and fO_2 conditions are high. The first two conditions might be expected with small grains.

Conclusions: Textural, chemical and mineralogical evidence in some sulfide-silicate fragments from comets is consistent with formation at high temperatures including crystallization from melts. Associations with Kool grains which may also have formed at high temperatures further strengthen this conclusion. The fragments may have formed at specific conditions where volatiles can, at least partially, be retained.

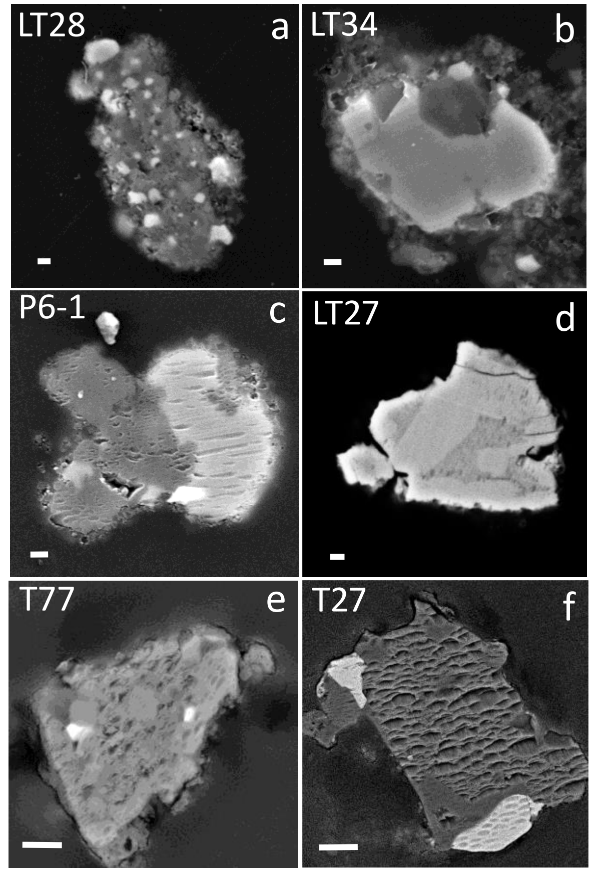

Fig 1: BSE images of 4 fragments from the giant cluster IDP (a-d) and 2 fragments from comet Wild 2 (e, f). a) LT28: Numerous pyrrhotites poikolitically enclosed in $En_{90}Wo_3$+albite+Na,Cr augite. b) LT34: Large pyrrhotite with embayed $En_{82}Wo_3$+minor Fo_{90} and Na,Cr augite. c) P6-1: Pyrhotite+$En_{85}Wo_4$+Fo_{86}. d) LT27: Exsolved Ni-rich pyrrhotite+pentlandite. e) Wild 2, T77: subterminal fragment showing Na,Cr-rich augite+Fo_{67}+Al,Si glass with two Fe,Ni sulfides (bright spots). f) Wild 2 T27: Terminal fragment showing $En_{87}Wo_4$+ Na,Cr-rich augite+pyrrhotite+euhedral pentlandite. Scale bars =1 µm.

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