**SUB-MICRON PYRRHOTITE-TAENITE GRAINS IN THE NUCLEUS OF COMET 81P/WILD 2** Frans J. M. Rietmeijer, Department of Earth and Planetary Sciences, MSC03 2040, 1-University of New Mexico, Albuquerque, NM 87131-0001, U.S.A. (fransjmr@unm.edu)

**Introduction:** The walls of the upper parts of bulbous (turnip) type, Stardust tracks are coated with vesicular, low-Mg silica glass with numerous nanometer (<100 nm) Fe-Ni-S and Fe-Ni inclusions [1,2]. The textures of this glass, including pyrrhotite fragmentation but not its low-Mg silica glass composition, are the result of the 6.1 km/s hypervelocity impact capture of micron size pyrrhotite grains in the Stardust silica aerogel tiles [3]. This hypervelocity impact experiment confirmed the initial observation, subsequently confirmed by many studies, that pyrrhotite is a common sub-micron mineral in the nucleus of comet 81P/Wild 2 [4]. Capture heating of the numerous nanometer-scale pyrrhotite fragments to close to their melting point caused continuous sulfur loss and formation of pure-Fe and low-Ni-FeNi nanograins [1,2,4]. Capture heating also caused the formation of Fe,S nanograins with apparent higher than $FeS_2$ sulfur contents [5]; some fraction or all could be oxidized, S-deficient, Fe-sulfides [6], which still needs to be demonstrated.

These reactions are examples of thermal decomposition and oxidation of low-Ni (up to ~2 at% Ni) pyrrhotite fragments of micron size Wild 2 pyrrhotite grains. They also highlight that the hypervelocity capture conditions caused unequilibrated mixtures of oxidized and reduced Fe-containing minerals to coexist in close proximity. This was observed by many other studies of comet Wild samples, *e.g* [7].

Keystone (C2044,0,41,0,0) cut from bulbous track #41 contains Fe-hot spots (possibly sulfides), ilmenite, V-rich chromite, and Fe-Ni compounds that are a mixture of FeNi-metal and ferric oxide [7]. A glass sample (C2044,2,41,3,6) of this track contained both low-Ni and high-Ni (up to ~12 at%) FeNiS nanograins scattered in the low-Mg silica glass (Fig. 1), which compliments the X-ray Microfocus Spectroscopy data [7] that Fe-sulfides and FeNi metal coexist in this track.

The compositions of FeNiS nanograins embedded in the low-Mg silica glass in bulbous track C2054,0,35 are highly variable. In sample C2054,0,35,51,3 they resemble those shown in Fig. 1 although the full range extends to include low-Ni Fe-metal. In two other samples, C2054,0,35,24,1 &7, the FeNiS nanograins include (1) low-Ni FeNiS, (2) high Ni (up to ~40 %at) FeNiS and pure FeNi (taenite) nanograins [2].

Tie lines between FeS and FeNi-metal compositions suggest that high-Ni FeNiS phases are the result of melting and mixing between these end-member compositions (Fig. 2).

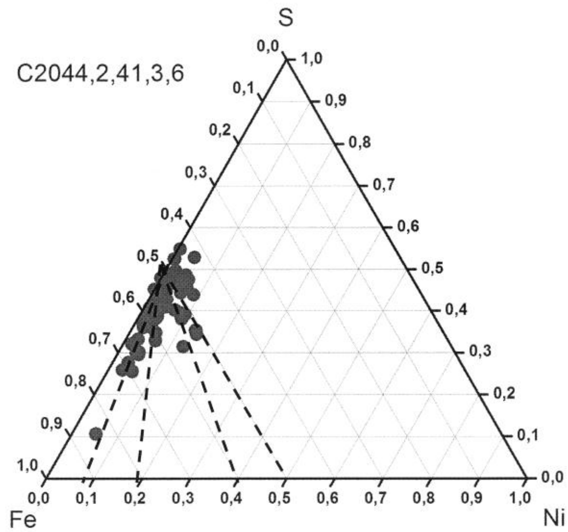


**Figure 1:** Fe-Ni-S (at%) ternary diagram of measured FeNiS nanograin compositions in low-Mg silica glass (modified after [2]). The dashed tie lines connect FeS-sulfides and possible FeNi metal compositions discussed in the text.

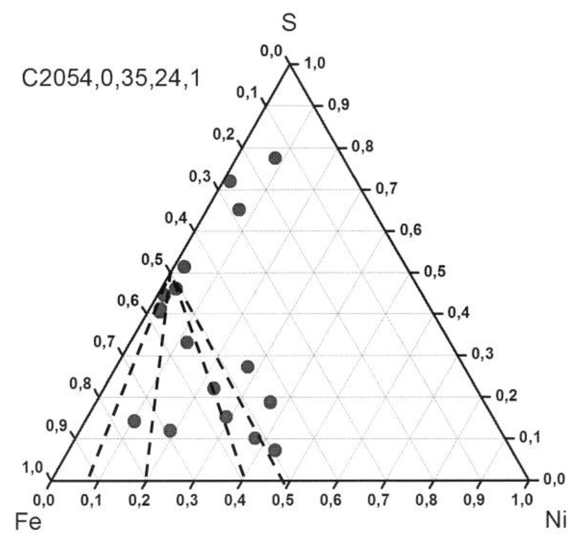


**Figure 2:** Fe-Ni-S (at%) ternary diagram of measured FeNiS nanograin compositions in low-Mg silica glass (modified after [2]). The dashed tie lines connect FeS-sulfides and the FeNi metal compositions discussed in the text.

**Taenite inclusion in pyrrhotite IDP:** Metallic iron with a taenite structure with a $Fe_3C$ rim was found in a chondritic IDP [8]. Taenite is present in UOCs and equilibrated OCs with Ni (at%) contents of 25-40%, 34% and 50-55% (cf. [9]). A ~10-μm-size low-Ni pyrrhotite IDP partially encloses a taenite grain (~1.7 x ~1.5 μm) with a 37 at% Ni bulk composition. This grain was flanked by mottled FeNi bands with 24 and 53 at% Ni and a narrow granular zone of taenite nanograins, ~12 at% Ni that is in direct contact with pyrrhotite [9]. A narrow Fe-oxide rim (Ni = 0–4 at%) that had formed during atmospheric entry flash heating locally covers the taenite grain [9]. So far this IDP, which is fragment F6 of cluster IDP L2011#21, is the only example of an extraterrestrial grain that contains both pyrrhotite and taenite grain [9].

There is a remarkable coincidence of taenite nickel contents in ordinary chondrites and this IDP and which define the intersections of the tie lines (dashed) in Figs 1 & 2 with the Ni-Fe side of the ternary diagrams. It is no coincidence that the apparent randomness of FeNiS nanograin compositions disappears and order emerges in the form of melting pyrrhotite-taenite grains. Whether each individual nanograin (i.e. each point in the ternary diagrams) was the result of a single pyrrhotite-taenite grain or whether the nanograin cluster in Fig. 2 is from a single pyrrhotite-taenite grain impacting in aerogel cannot be assessed at this time.

**Discussion:** The key to understanding range to understanding the observed FeNiS nanograin discussed and shown compositions in Figs 1 & 2 is found in the Fe–Ni phase relationships. The solidus and

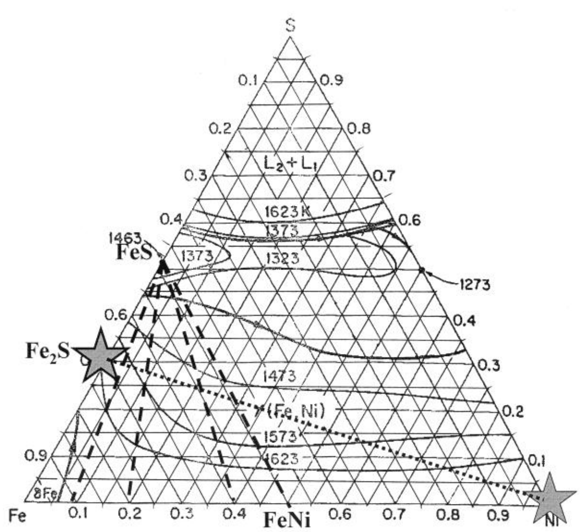


**Figure 3:** Fe-Ni-S (at%) ternary diagram of measured FeNiS (template modified after ref. [10]) showing the FeS - FeNi tie and the reaction products of the reaction FeS + FeNi → $Fe_2S$ + Ni (dotted line; stars) lines discussed in the text. Temperatures are degrees Kelvin.

liquidus in this phase diagram are slightly curved with a thermal minimum of ~60 at% at ~1700K which is slightly lower than the Ni melting (1728K) and iron melting (1807K) points. They are also spaced closely together. When heating taenite Ni ~40 at% close to its melting point there will be no preferred specific melt composition or single FeNi solid compositions. Kinetic factors will define the ultimate behavior. Still, the similar FeNi-metal compositions in ordinary chondrites and IDP L2011#21 suggest external controls. Here, these compositions are accepted as end-members of mixing line in the Fe-Ni-S (at) system (Figs. 1-3).

Heating a pyrrhotite-taenite grain to above its melting point to around 1700K will yield FeNiS melts with compositions located somewhere on the tie lines shown in Fig.3 according to reactions, FeS + FeNi → FeNiS + Fe (eq.1) whereby the exact FeNi phase composition will be defined by unpredictable kinetic factors. The Fe droplets will add to the Fe-metal nanograins. So far, pure Fe-metal nanograins in the vesicular low-Mg silica glass of Stardust tracks was considered either indigenous [7] or the end product of compete pyrrhotite desulfurization [1,2,4]. While speculative, a corollary of the proposed model might be the physical separation of FeNiS melt droplets [2,11] into individual Fe-sulfide and Ni metal droplets according to the (idealized) reaction, $Fe_2NiS$ → $Fe_2S$ + Ni (Fig 3: stars and dotted line). These predicted pure Ni nanograins remain elusive but sample C2054,0,35,24,7 [2] contains almost pure $Fe_8Ni_2$ suggesting that this reaction might be feasible. This reaction would add 'secondary' sub-sulfur Fe-sulfides. The bulbous parts of Stardust tracks were a mélange of kinetically defined nano-environments.

**Conclusions:** This work predicts the presence of pyrrhotite-taenite grains among the smallest grains in the comet Wild 2 nucleus in addition to single pyrrhotite. The presence of pure taenite cannot be ruled out. Additional work is necessary to confirm the model.

**References:** [1] Rietmeijer F. J M. (2009) *Meteoritics & Planet. Sci., 44,* 1121-1132. [2] Leroux H. et al. (2008) *Meteoritics & Planet. Sci., 43,* 97-120S. [3] Ishii H. A. et al. (2008) *Science, 319,* 447-450. [4] Zolensky M. E. et al. (2006) *Science, 314*, 1735-1739. [5 Rietmeijer F. J. M. (2010) *LPS XLI,* Abstract #1239. [6] Rietmeijer F. J M. (2004) *Meteoritics & Planet. Sci., 39,* 1869-1887. [7] Bridges J. C. et al. (2010) *Meteoritics & Planet. Sci., 45,* 55-72. [8] Fraundorf P. (1981) *GCA, 45*, 915-943. [9] Rietmeijer F. J. M. (2004) *LPS XXXV,* Abstract #1060. [10] Hsieh K.-C. et al. (1987) *High Temp. Sci., 23,* 17-38. [11] Velbel M. A. and Harvey R. P. (2009) *Meteoritics & Planet. Sci., 44,* 1519-1540.

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