Refractory metal nugget inclusions in cometary materials from the edge of the solar system

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Submicron refractory metal nuggets (RMNs) composed of Os-W-Ir-Mo-Ru-Pt-Fe-Ni were found in oxide- and silicate-rich refractory objects (2 – 15 μm) from comet Wild 2 and a cluster interplanetary dust particle (IDP) of probable cometary origin. The RMNs occur in a calcium-aluminum-rich inclusion (CAI) (spinel+melilite+$An_{97\text{-}100}$+ diopside/fassaite), an Al-rich chondrule (spinel+$An_{94\text{-}96}$+diopside) and an amoeboid olivine aggregate (AOA) ($Fo_{88\text{-}94}$+An_{98}+diopside) [1] and may have originated as condensates in the solar nebula. Like counterpart RMNs in CAIs from chondrites, the refractory metal grains have variable composition from nugget to nugget [2,3], however, the RMNs in the comet samples are generally richer in Fe and Ni and have lower abundances of the most refractory elements. This suggests that the RMNs from the comet samples formed at the lower temperature end of the ~1450 – 1620 K temperature range where most RMNs likely condensed [2].

In chondrites, RMNs are believed to be the first condensates from a cooling gas of solar composition at $P = 10^{-4}$ bar [4]. Most are found in CAI minerals, principally spinels, although RMNs have also been observed in hibonite, melilite and forsterite [4,5,6] as well as presolar graphites [7]. In the Paris meteorite, the least altered CM chondrite, the highest temperature RMN compositions correlate with the highest temperature host phases [6]. The observed comet RMNs are the lower temperature alloys and reside largely in anorthite, a late-stage refractory mineral (In the AOA, RMNs are in forsterite or diopside.). In general, the mineralogy and bulk compositions of the oxide/silicate host grains from the comet samples are most consistent with more evolved, lower temperature refractory nebular materials [1]. It appears the observed RMNs and host phases that were incorporated into comets were derived from environments in the nebula that did not preserve the highest temperature refractory materials.

[1] Joswiak and Brownlee (2014), *45th LPSC* abstract #2282 [2] Berg *et al* (2009), *ApJ* **702**, L172-L176 [3] Liffman *et al* (2012), *Icarus* 221, 89-105 [4] Palme and Wlotzka (1976) *EPSL* **33**, 45-60 [5] Harries *et al* (2012), *MAPS* **47**, 2148-2149 [6] Hewins *et al* (2014), *GCA* **124**, 190-222 [7] Croat *et al* (2013), *MAPS* **48**, 686-699