NORTHWEST AFRICA 12969: DIAMONDS AND SIDEROPHILE-ELEMENT EVIDENCE SUGGEST KINSHIP, OR AT LEAST PETROGENETIC ANALOGY, WITH EXTREME-MAGNESIAN UREILITES

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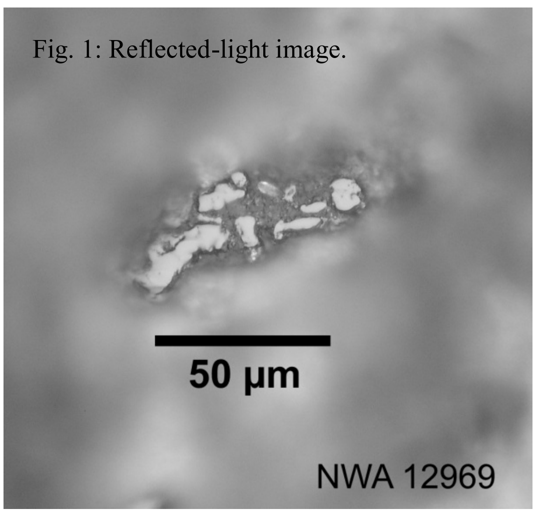
The NWA 12969 achondrite has been classified as ungrouped [1]. It consists mainly of two silicate phases, nearly pure enstatite pyroxene (our 24 analyses average En97.9Wo1.1) and nearly pure Mg-olivine (71 analyses average Fo99.1), along with minor FeNi metal, now mostly weathered into Fe-oxides. We also found minor medium-Ca pyroxene, two analyses averaging En83Wo16. The overall pyroxene/olivine ratio is about 2:1, but subject to great sampling uncertainty, as large areas are almost devoid of olivine. Our study reveals mineralogical and geochemical similarities with ureilites. The most magnesian precedent among ureilites, the ALH 82106 pair group, has about Fo95 core olivines [e.g., 2; however, cf. 3].

The only known previous examples of micrometer-scale diamonds in nonchondritic meteorites are rare occurences in shocked irons, and many occurences in ureilites, especially among highly shocked ureilites. NWA 12969 is mildly shocked (shock stage ~S3), its pyroxene having been transformed into polygranular aggregates with some polysynthertic twinning. Most ureilite diamonds are only a few micrometers across; grains that are multiple tens of micrometers in size are uncommon [4]. A single grain of "at least" 100 µm is the largest known [5].

The first indication of diamonds in NWA 12969 was difficulty with sawing as we produced our three large thin sections. A search using reflected light microscopy quickly revealed numerous ultra-high relief grains (e.g., Fig. 1) that were confirmed to be at least nearly pure C using EDS x-ray analysis on our SEM. (The nondiamond portion of Fig. 1 is out of focus because the focused-upon diamond clump projects far above the other minerals.) This diamond clump is 70 µm long; its largest single contiguous-appearing component (elongated in the same approximate direction as the overall clump) is 30 µm long. The NWA 12969 diamonds are abundant and large by ureilite standards.



The meteorite's siderophile element depletion pattern manifests further similarity with ureilites. Our INAA data (from a 0.7-g whole-rock powder) show only mild depletions for the arch-siderophile elements: CI-normalized Os = 0.71, Ir = 0.68; and deeper depletions for less ideally siderophile elements: CI-normalized Co = 0.27, Ga = 0.18, Ni = 0.175, Au = 0.17, Sb = 0.07. This general pattern is typical of ureilites and probably resulted from asteroidal core formation involving separation of a considerable proportion (several wt%) of S-rich metallic melt, before far-less-efficient separation of the remaining S-poor Fe-metal [6]. Sulfide is extremely rare in NWA 12969 [1], although we did detect a trace of daubréelite, associated with distinctive phosphide-dominated micro-symplectites.

The whole-rock Fe content of 3.8 wt% is consistent with the ureilite Fo vs. bulk-Fe trend. The bulk Fe result also, in conjunction with our mafic silicate analyses, shows that ~85% of the meteorite's original Fe was in reduced form (FeNi-metal) prior to terrestrial weathering. The olivines have scattered tiny metal inclusions, and olivine analyses show barely detectable reverse zoning, although (perhaps unsurprisingly, since even the most ferroan NWA 12969 olivine is almost pure Fo) these traits are far less obvious than in typical ureilites.

Not all of the available evidence points neatly towards an affinity with ureilites. The oxygen-isotopic composition [1] resembles ureilites in being well below the terrestrial line, but falls almost unprecedentedly far to the high-Δ^{17}O side of the ureilite Fo vs. Δ^{17}O trend. Our bulk-rock result for zinc (CI-normalized, 0.076) is far more depleted than in normal ureilites (in most cases >0.5; and ALH 82106 is no exception); this may reflect of volatilization at some stage in the petrogenetic history of NWA 12969. The Ni/Au ratio is far higher than previously known for unweathered ureilites (but data for As confirm that NWA 12969 has been significantly weathered).

More work is needed, most obviously on stable isotopes (e.g., Cr), which show that despite their high carbon contents ureilites are descended from the "noncarbonaceous" binary reservoir of Solar System materials [7].

References: [1] Irving A. et al. (2020) *Meteoritical Bulletin* entry for NWA 12969. [2] Goodrich C. A. (1992) *Meteoritics* 27: 329. [3] Sinha S. K. et al. (1997) *GCA* 61: 4235. [4] Nabiei F. et al. (2018) *Nature Commun.* 9: 1327. [5] Nestola F. et al. (2020) *Proc. NAS* 117: 25310. [6] Warren P. H. et al. (2006) *GCA* 70: 2104 [7] Warren P. H. (2011) *EPSL* 311: 93.