

STRANGELY Ca-POOR METASOMATIC PYROXENES IN UNANNEALED EUCRITES

Jason Utas¹ and Paul H. Warren¹, ¹Department of Earth, Planetary and Space Sciences, University of California, 405 Hilgard Avenue, Los Angeles, CA 90095, USA; jutas@ucla.edu.

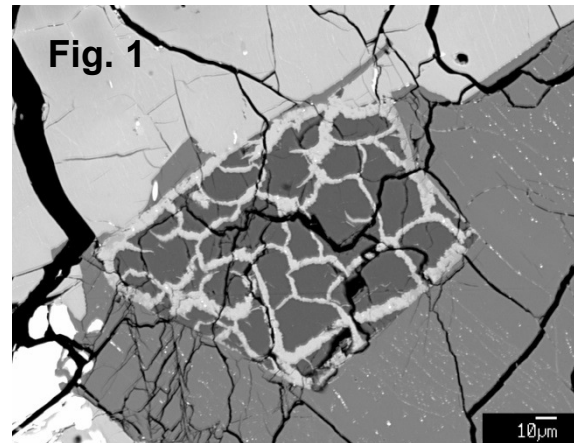
Most of the eucrite meteorites have undergone an annealing process that, inter alia, caused their pyroxene (px) compositions to become equilibrated to low-Ca and high-Ca components (exsolved lamellae) very near a single compositional tie-line. The very few eucrites that avoided major annealing merit scrutiny as more direct links to igneous origin. Takeda and Graham [1] called the unannealed eucrites “pristine”. However, evidence has accumulated in recent years [e.g., most notably 2] suggesting that even the unannealed eucrites tend to be far from completely pristine-igneous, as they commonly feature secondary veining (often dominated by an igneously improbable combination of fayalitic olivine and extremely Na-poor plagioclase) within their px. The interpretation of [2] (cf. [3]) has been that some type of secondary volatile-rich fluid precipitated these vein materials. Here we describe a new eucrite, Northwest Africa 11040, that shows a similar yet novel type of secondary vein-alteration, and thus further constrains the role of volatile-rich fluids in the crust(s) of the eucrite parent body(ies).

NWA 11040 (total known mass 13 g) is also unusual in having a relatively high proportion of Fe-metal: in thin section about 0.5 vol% (~1.1 wt%; a minor fraction of which has been oxidized by Saharan weathering). If anything this section may underrepresent the whole rock. The high metal content was conspicuous macroscopically, before we began our study. The metal is almost Ni-free (undetectable by EPMA, despite extra-long count duration and high beam current; < 0.05 wt%), with 0.15-0.23 wt% Co. INAA data also show low Ni, and in general a fairly nondescript eucrite bulk-rock composition, e.g., Na = 4.1 mg/g, Sc = 28 µg/g, Cr = 1.9 mg/g, Fe = 138 mg/g, Sm = 3.2 µg/g. The high metal abundance suggests a possibility of in-situ reduction, and indeed the rims of many px grains show a corroded texture [4], possibly formed when FeO reduction caused partial decomposition of the px.

In our previous work on secondary veining within eucrites [3], the near-total confinement of the veins to within (or at the rims of) pyroxene has been seen as a key constraint. If the veins formed by injection of melt, we would expect vein abundance to be similar in the other major phase, plagioclase. In NWA 11040, the secondary veins are dominantly anomalous-composition (FeO-rich, CaO-poor) px instead of olivine (the very minor olivine is Fo29-31), a near precedent for which is the px found lining the olivine veins of NWA 1000 [5]. But an even more extremely

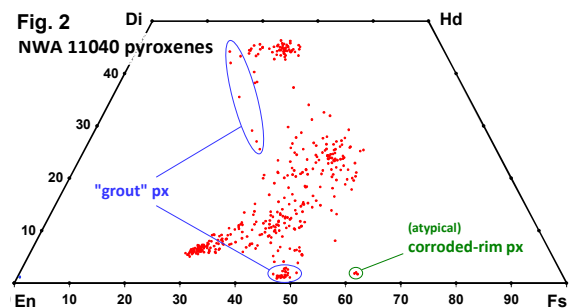
anomalous px composition is found in some places within NWA 11040.

The setting for this anomalous px is illustrated in Fig. 1, a backscattered electron image of NWA 11040

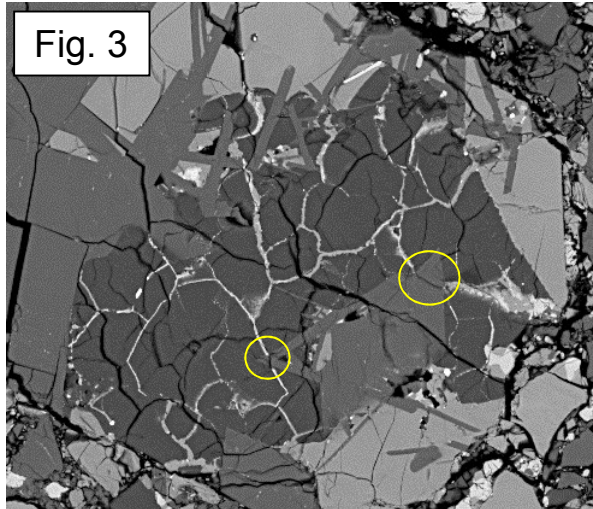


in which the darkest grey phase is silica (cristobalite?; birefringence is extremely low and the material may even be glass), and the light veins that weave through it are the anomalous-composition pyroxenes.

Numerous similar veined-silica objects are found in NWA 11040, and also in Pasamonte (although the veins tend to be thinner in Pasamonte). The texture resembles grouted tiles, with the px being the grout and the silica forming the tiles. A typical composition of the anomalous px is En52Wo1.3 (Fig. 2). In some



grouted-tile areas a complementary high-Ca composition, about En39Wo44, is also (or instead) found. In this and other unannealed eucrites, the lowest Ca content for igneous px with *mg* near 50 mol% (like the En52Wo1.3 composition) is about Wo8. In order for compositions such as these to develop out of normal igneous precursors by simple dry annealing/exsolution, an impossibly low temperature of equilibration would be implied, roughly 550°C [6]. Yet NWA 11040 is not an annealed eucrite. Its pyroxenes retain diverse une-



quilibrated compositions and exsolution lamellae are undetectable optically and only barely detectable at SEM scale. Some extraordinary process formed the NWA 11040 and Pasamonte “grout” pyroxenes.

Another interesting aspect of the grouted-tile objects, manifested best in Pasamonte (Fig. 3; view is ~ 0.2 mm across), is that the grout-veins (usually almost purely pyroxene) show a conspicuous absence, a void, in places where the crack into which the grout has filled happens to extend across a projection of plagioclase within the block of tiled silica (yellow circles in Fig. 3). As with the olivine-dominated veins in px among other unannealed eucrites, the process that left the grout veins was *host-phase selective*. It was not merely a matter of a condensed phase (melt) filling in the space and then crystallizing (improbably) into near-pure px. We infer that a fluid was involved, and thus precipitation of px (or elsewhere, olivine) against the walls of the cracks was favored or not depending upon the suitability of the crack-wall matter as a site for nucleation and growth of the vein-fill phase(s).

The mineralogy of the vein-fill matter appears broadly consistent with this scenario. Where a eucrite-transiting fluid reacted with a pyroxene host with $M/Si = 1$ (M standing for divalent mafic cations, $MgO+FeO+CaO$), the secondary depositions typically consist largely of olivine with $M/Si = 2$. But in the grouted-tile objects, where a similar fluid reacted with a silica host with $M/Si = 0$, the secondary depositions consist largely of pyroxene which has a more moderate M/Si of 1.

Although we infer that formation of the secondary veins (both types) probably involved a fluid phase, we are not yet ready to infer much about the composition of the fluid (if H_2O -bearing, i.e., in a strict sense “aqueous”, probably nothing like a typical terrestrial fluid, where H_2O dominates the composition; cf. [7]);

or about the relationship between the vein-filling alterations and the redox processing of NWA 11040 and several other unannealed eucrites [4, 8]; or whether the fluid might have been involved with an accompanying melt (shock-melt?) component as part of the overall secondary processing. Additional study of unannealed samples should help to constrain the general phenomenon of secondary, volatile-driven alteration of the eucrites [2, 3, 7].

References: [1] Takeda H. and Graham Takeda H. and Graham A. L. (1991) *Meteoritics* **26**, 129–134. [2] Barrat J. A. et al. (2011) *Geochim. Cosmochim. Acta* **75**, 3839–3852. [3] Warren P. H. et al. (2014) *Geochim. Cosmochim. Acta* **141**, 199–227. [4] Warren P. H. and Utas J. (2017) *Lunar Planet. Sci.* **48**, this volume. [5] Warren P. H. (2002) *Lunar Planet. Sci.* **33**, abstract #1147. [6] Lindsley D. H. (1983) *Am. Mineral.* **68**, 477–493. [7] Warren P. H. et al. (2017) *Meteor. Planet. Sci.*, in press. [8] Mittlefehldt D. W. and Peng Z. X. (2015) Met. Soc. meeting abstract #5342.