GRAIN BOUNDARY GLASSES IN PLUTONIC ANGRITE NWA 4590: EVIDENCE FOR RAPID DECOMPRESSIVE PARTIAL MELTING AND COOLING ON MERCURY?

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Discovery: A 212.8 gram stone found in many fragments in June 2006 south of Tamassint oasis in the Morocco-Algeria border region represents a new type of angrite lithology, unlike any of the 3 coarse grained metamorphic examples or 7 fine grained "basaltic" to quench-textured examples known previously [1]. This specimen exhibits unique features that have important implications for the size, cooling history and tectonics of the angrite parent body (APB).

Petrography: This very fresh, fusion-crusted specimen has a coarse grained (0.6-12.2 mm) plutonic igneous cumulate texture (see Figure 1), and is composed of Al-Ti-rich clinopyroxene (33%) with rare pigeonite exsolution lamellae, pure anorthite (28%), Ca-rich olivine (14%) with prominent exsolution lamellae of kirschsteinite, kirschsteinite (5%) with exsolution lamellae of olivine, ulvöspinel (18%) and accessory glass, troilite, merrillite, *Cl-bearing* Ca silico-phosphate and metal. Some anorthite occurs as subhedral grains partially enclosed within large ulvöspinel grains, but most occurs as intercumulus aggregates. Clinopyroxene (Al-Ti-diopside) is strongly zoned with paler colored, corroded cores surrounded by darker purple-brown mantles and distinct rims (see Figure 1). Mineral compositions: clinopyroxene ($Fs_{20.8-33.3}Wo_{53-54.9}$, Al_2O_3 = 5.7-9.4 wt.%, TiO_2 = 0.9-2.9 wt.%, FeO/MnO = 85-278), integrated olivine ($Fa_{68.1}Ln_{12.2}$, CaO = 7.3 wt.%, FeO/MnO = 70-87), integrated kirschsteinite ($Fa_{52.4}Ln_{36.6}$, FeO/MnO = 73-82), ulvöspinel (TiO_2 = 27.6 wt.%, Al_2O_3 = 5.5 wt.%, Cr_2O_3 = 0.5 wt.%). The very ferroan olivine and kirschsteinite compositions (Figure 3) imply continued re-equilibration with liquid after pyroxene crystallized.

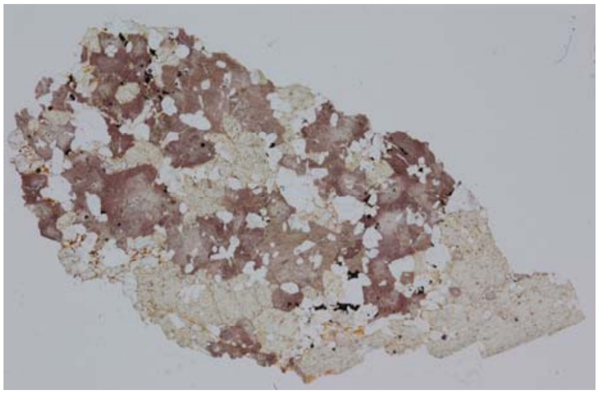
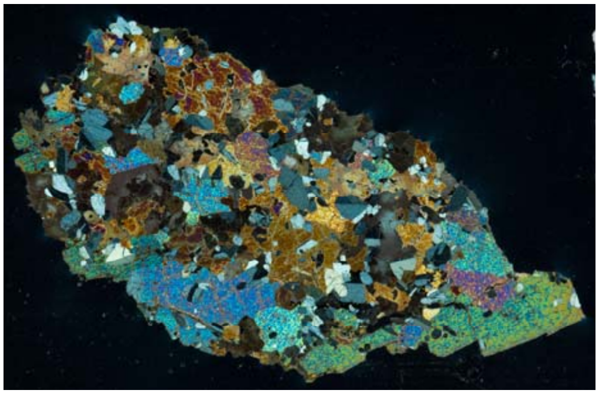


Figure 1: Optical thin section image in plane-polarized light (above) and cross-polarized light (below), showing zoned Al-Ti diopside-hedenbergite (purple-brown), kirschsteinite and olivine (pale yellow-green), intercumulus anorthite (white) and ulvöspinel (black) Width of field is 2 cm.



Glasses: Present along grain boundaries (notably between anorthite and ulvöspinel, but also around and cutting across troilite grains) are 5-50 μm wide, curvilinear zones of glass and apparently re-precipitated kirschsteinite, clinopyroxene, olivine, anorthite and troilite, all of which truncate kirschsteinite exsolution lamellae in primary olivine (see Figure 2).

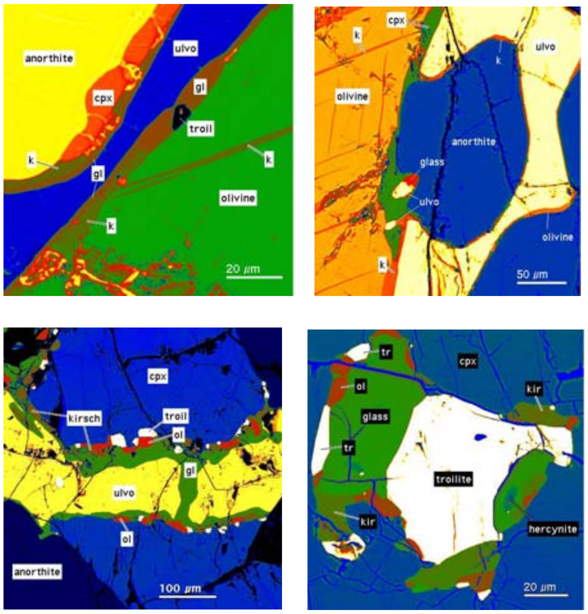


Figure 2: False-color BSE images of glasses and associated daughter minerals.

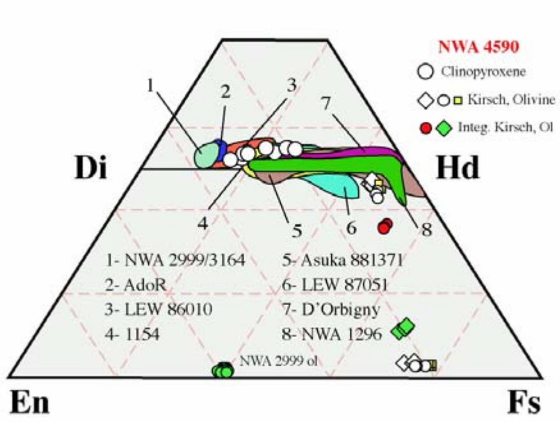
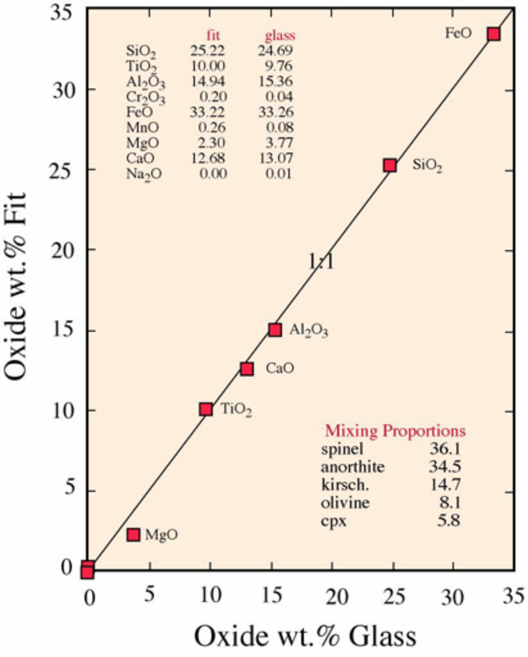


Figure 3: Clinopyroxene compositions for NWA 4590 span those in plutonic metamorphic angrites (1-3) and in basaltic to quench-textured angrites (4-8). Integrated olivine and kirschsteinite compositions imply pre-exsolution equilibration at ~1000°C, using the solvus of [2].

Glass compositions plot close to a mixing line between anorthite and ulvöspinel (Figure 4), but there must be contributions from olivine, clinopyroxene and kirschsteinite to the melting reaction(s), as well as modification of liquid compositions by precipitation of these phases and troilite. We interpret these features to be the product of eutectic-like partial melting, grain boundary mobilization and subsequent crystallization on the ancient APB. The geometry of melt zones "wetting" grain boundaries and the preservation of exsolution lamellae imply very rapid melting then cooling.



A Possible Mercury Connection: Papike et al. [3] made the suggestion that angrites might be samples from Mercury based in part on the systematics of plagioclase compositions and Fe/Mn ratios in constituent mafic minerals in comparison with basaltic rocks from Earth, Moon, Mars and Vesta. An unusual mineral chemical attribute of angrites is that the Fe/Mn ratio in pyroxene is greater than that in olivine (opposite to the case for other planetary mafic rocks), and this is borne out by data for the latest specimen. Of course, in the absence of any "ground truth" rock samples from Mercury, the possibility of a Hermean origin for angrites rests only on circumstantial arguments, as we have discussed elsewhere [4].

Nevertheless, it seems that angrites must derive from a large planetary body present in the very early Solar System that is capable of internal melting to produce differentiated ultramafic rocks by 4562-4558 Ma [5] (and possibly also substantial vertical tectonic activity). The distinctive grain boundary glass in the NWA 4590 implies a very rapid melting and cooling event, more plausibly caused by decompression rather than heating (after igneous accumulation). This glass is compositionally different from glass in D'Orbigny; however, the latter contains a trapped "solar-rich" noble gas component [6] typical of large differentiated planets with former magma oceans. If the APB indeed is (or was) a large planet, then perhaps the diverse types of angrites derive from early collisional stripping [e.g., 7] of its outermost (possibly more ferroan) lithosphere. The present surface of the remaining planet (the former deep mantle lithosphere) need not necessarily match the compositions of angrites, and it might be more magnesian. Spectral data have been interpreted [8] to constrain the bulk FeO content of surface materials on Mercury to be less than 3-6 wt.%, whereas all angrites contain more FeO than this (up to 25 wt.% FeO). The case for Mercury as the APB is far from proven, but it remains a viable hypothesis.

References: [1] Irving A. J. et al. (2006) *EOS, Trans. AGU* **87**, *Fall Meet. Suppl.*, #P51E-1245. [2] Mukhopadhyay D. and Lindsley D. (1983) *Amer. Mineral.* **68**, 1089-1094 [3] Papike J. J. et al. (2003) *Amer. Mineral.* **88**, 469-472 [4] Irving A. J. et al. (2005) *EOS, Trans. AGU* **86**, *Fall Meet. Suppl.*, #P51A-0898; Kuehner S. M. et al. (2006) *LPS XXXVII*, #1344 [5] Markowski A. et al. (2007) *Earth Planet. Sci. Lett.*, submitted [6] Busemann H. et al. (2006) *Geochim. Cosmochim. Acta* **70**, 5403-5425; Owen T. and Bar-Nun A. (2000) *In* Origin of the Earth and Moon, p. 459-473, Univ. Arizona [7] Horner J. et al. (2006) *Roy. Astronom. Soc. Nat. Mtg.*, abstract #J.7 [8] Robinson M. S. and Lucey P. G. (1997) *Science* **275**, 197-200.