
P. H. Warren¹ and K. Sawchuk¹, ¹Earth, Planet., Space Sciences, UCLA, Los Angeles, CA 90095 (pwarren@ucla.edu).

Eucrites seldom show great compositional diversity. Modal silica/(silica+plagioclase) is never greater than 0.24 (the Caldera gabbro); in the vast majority of cases <0.15 [1, 2]. Yet within eucrite breccia Northwest Africa (NWA) 10553, specifically as several tens of discrete enclaves, frequently ovoid and up to 3 mm across, [3] found a fundamentally novel variety of silica enrichment: silica consistently linked (intergrown) with augitic pyroxene, with only minor proportions of other phases, and with feldspar conspicuously near-absent. As they knew of no existing name for such a material, [3] referred to it as silica-augite intergrowth (SAI). Although for this work we used Raman spectroscopy to determine that the silica phase is quartz (arguably the term QAI would add precision), we retain the term SAI from [3].

Mineralogical-textural studies are complicated by moderate Saharan weathering, thermal metamorphism, plus intense shock metamorphism. Plagioclase and the silica phase(s) show tortured crystallinity with local isotropism. Tiny shock-melt veins are pervasive. In general, although brecciation and even shock-melting occurred pervasively on a sub-mm scale, there is little evidence of brecciation-displacement at larger scales. Although texturally battered and brecciated, the rock may be essentially monomict, or possibly polymict.

The 2016 study of NWA 10553 [3] focused mainly on three sequential moderately large (4 cm³) polished sections, none with macroscopically conspicuous clasts. For this work, we produced a set of four large (~10 cm², rectangular) thin sections centered around one conspicuously coarse-grained (and in part, leucomagmatic) 1.5-cm clast. Our hope was that this clast might be a contiguous mass of originally igneous material, consisting in part of SAI. Indeed it is, and does.

In NWA 10553 groundmass [3], SAI is found mostly as seemingly isolated, often ovoid, masses (Fig. 1). With augite Al₂O₃ content averaging 0.95 wt%, this enclave’s bulk composition has merely 0.7 wt% Al₂O₃. Some large SAI areas elsewhere in NWA 10553 have more augite than silica, but these tend to be less ovoid, more internally heterogeneous in silica/pyroxene ratio, and (at pyroxene-dominated margins) less obviously distinct from normal basaltic augite-silica associations.

SAI mineral compositions are mildly evolved compared to the rest of NWA 10553. The minor SAI plagioclase is An85-89, whereas average non-SAI plagioclase is An92 [3]. SAI pyroxenes are consistently ferroan, averaging En33Wo41 for augite and En40Wo1.7 for (largely exsolved) orthopyroxene; whereas non-SAI pyroxenes are mostly toward the magnesian ends of the ranges En32-36Wo–44 and En42-50Wo2 (augite and opx). Abundance of phosphate (merrillite) appears to be at roughly the same trace level within SAI enclaves as in the rest of the rock. The rock’s scattered trace of olivine (Fo32-35), possibly of secondary/metamorphic origin, is found exclusively outside the SAI enclaves.

The large 1.5-cm clast has the relict igneous texture (discernible through the shock, thermal-metamorphic, and weathering effects) of a cumulate. Pyroxenes are equant and typically 3-4 mm across, although some that meet this general description consist of 0.5-mm equant-granular domains of intergrown low-Ca pyroxene and augite. Plagioclases are equant to fat-lathy, and typically about 2 mm in maximum dimension.

We used INAA and fused-bead EPMA to determine bulk compositions of two adjacent 210-310 mg chips from the NWA 10553 groundmass. Results (e.g.

Fig. 1: SEM x-ray map of an uncommonly large (3×2 mm) SAI enclave, with quartz = shocking pink, orthopyroxene = teal blue, plagioclase = red, augite = dark grayish green, and ilmenite = bright green. This enclave contains only 1 vol% plagioclase; the rest of it is mainly silica with lesser augite and traces of ilmenite, opx and Cr-spinel (bright blue). SAI s consistently have approximately this grain size, and augite >> opx.
Sc = 20 µg/g, Lu = 0.138 µg/g, mg = 49 mol%) suggest the rock is dominantly (or purely, if monomict) of cumulate origin. If it is monomict, or near-monomict, the cumulate formed from a relatively evolved, ferroan and Ti- and REE-rich, parent magma.

A mass of SAI occurs very near one end of the host cumulate clast (Fig. 2), and shows clear signs of being a continuation of the mineralogy and texture of the adjoining cumulate material. As cumulates often do (e.g., “rhythmic layering”), the host clast shows a high degree of mineralogical heterogeneity. Near the SAI the mineralogy trends into a higher pyroxene/plagioclase ratio and uncommonly abundant quartz, augite, and ilmenite. Immediately surrounding the SAI is a zone of near-pure augite, broken in places by large silica and ilmenite grains. Plagioclase is virtually absent within the SAI, and rare in the general vicinity.

Fig. 2: SEM backscattered-electron image of the SAI-bearing corner of the NWA 10553 cumulate clast. Field of view is 4.1 x 4.6 mm. Phases identified by abbreviations include plagioclase = pl, quartz = q, and ilmenite = i. Veins of Ca-carbonate are nearly same shade of grey as plagioclase. Slightly lighter grey within pyroxene is exsolved or granular augite (also the dominant pyroxene within and immediately surrounding SAI). Dominant lighter regions within large cumulus pyroxenes are orthopyroxene.

The host cumulate clast also shows mineral-compositional heterogeneity. Pyroxene at the far end of the clast is consistently magnesian (mg = 53 mol% in low-Ca pyroxene and ~ 65 in associated augite exsolution), but in the direction of the SAI end of the clast mg gradually, systematically, becomes more ferroan, ending at 41 in low-Ca pyroxene and 56 in augite. Thus, both the mineral abundances and the mg of pyroxene become more evolved in proximity to the SAI. This is a fairly normal igneous trend, although it is unusual for cumulates to evolve in mg, in addition to modal abundance (cumulus phases aggregate in notoriously heterogeneous ways), over such a short distance.

What is not at all normal, and remains puzzling, is the trend of extreme diminution in plagioclase/pyroxene ratio that we find associated with the SAI culmination of the igneous-evolution trend. As noted by [3], “the extreme Al₂O₃ depletion (near-absence of feldspar) rules out origin from pockets of late-stage melt, unless some weird shift in environmental conditions drove plagioclase off the liquidus until the residual melt was squeezed out.” Oxygen fugacity does not appear to have been abnormal. The trace of Cr-spinel in the Fig. 1 SAI consistently shows stoichiometry implying near-zero Fe₂O₃, albeit spinel elsewhere in the rock shows up to 1.4 wt%. Nonetheless, we are now forced to consider that “some weird shift” may indeed have occurred. Was it conceivably a case of admixture into or exsolution of water-rich fluid within the parent magma? In principle, water has the right effect: shifting the pyroxene-plagioclase boundary to where a plagioclase-pyroxene cosaturated melt becomes undersaturated in plagioclase [4].

The origin of the NWA 10553 SAI enclaves remains mysterious. However, we now know the igneous-cumulate context in which they formed. We also have evidence from the host clast that the context for cumulate genesis on the eucrite parent asteroid was in some cases a remarkably small (or at least, remarkably thin), decimeter-scale, intrusive body.