

CHROMIUM-SILICATES, FELDSPARS AND HIGHLY SILICIC GLASSES FORMED FROM FELSIC MELTS IN POST-DEPRESSURIZATION FERROAN UREILITES, ESPECIALLY LEW 88774

Paul H. Warren and Heinz Huber

Institute of Geophysics, UCLA, Los Angeles, CA 90095-1567, USA (pwarren@ucla.edu)

Depressurization is the dominant process that produces mantle melts on Earth. Depressurization had equally profound but quite different effects in the evolution of ureilite meteorites. The second most abundant type of achondrite, ureilites formed as anatectic restites (olivine + pyroxene + minor, 0.2-6 wt%, carbon) in the mantle(s) of carbonaceous asteroid(s). In ureilites, depressurization was probably initially caused by impact disruption of the asteroid(s), and involved only a few tens of bars. Despite a simultaneous abrupt transition from the anatectic thermal regime into one of rapid cooling, depressurization triggered a series of chemical transformations, starting with oxidation of the carbon, the oxygen coming from reduction of olivine (rims only) and minor melt components [1].

In some of the most FeO-rich ureilites, post-depressurization redox (DR) had consequences beyond the usual olivine-rim effects. Warren [2] described evidence for reduction of Cr₂O₃ from Cr-spinel (cm) into CrO-rich silicates in NWA 776. In this work, we describe the corresponding but more diverse suite of DR phases in LEW 88774, and discuss the origin of these materials, including the highly silicic (typically ~70 wt% SiO₂) glasses that are found in contact with almost all reduced ureilitic Cr-spinels.

LEW 88774 is by far the most cm-rich ureilite, 3-6 vol% [3-5]. Early work [3,4] documented the presence of Cr-rich sulfides and carbides, (Fe,Cr)₂C with Fe/Cr wt. ratio generally ~2, clustered near the cm's. The long, thin, arcs of CrO-rich (up to 40 wt%) silicates that occur shortly beyond the rims of LEW 88774 cm's are very similar to the corresponding materials in NWA 776; and like the NWA 776 Cr-silicate arcs [6], these LEW 88774 arc materials were in 2001 misinterpreted as uvarovitic (Cr³⁺-rich) garnet [7]. These Cr-silicate arcs occur as growths "in" toward cm from semi-adjacent olivine; not fully adjacent because there is a layer of silicic glass between arc and cm. It now appears unlikely that the Cr-silicate arc phase was ever a garnet of any kind. The hypothesis that this material is (or formerly was) garnet fails the test of stoichiometric charge balance, i.e., the Cr cannot be mainly Cr³⁺.

A small minority of the Cr-silicate arcs in LEW 88774, occurring as CrO-rich (up to 28 wt%) growths "in" toward cm from semi-adjacent low-Ca pyroxene, have much higher Si/O ratios. We concur with the interpretation [7] that these high-Si/O Cr-silicates originated as a variety of pyroxene.

Both varieties of Cr-silicate occur mainly as symplectitic intergrowths [4] on a scale so uniformly fine, it is generally impossible, by SEM or *e*-probe, to resolve the compositions of their two (or more) major constituent phases. It seems unlikely that the symplectites are primary-igneous. In the low-Si/O variety, the stoichiometry from *e*-probe analyses for the symplectitic mixture of phases is consistently close to that of olivine: M₂SiO₄, where M is CrO+MgO+FeO+CaO. The earliest portions of the arcs, grown directly onto the reduced rims of large olivines, generally appear almost as a single massive phase (these layers are also distinctly Ca-rich, albeit the absolute degree of Ca enrichment is diverse); and the most massive of such areas show M₂SiO₄ stoichiometry very close to that of olivine. Likewise, in the low-Si/O variety, the stoichiometry is consistently close to that of pyroxene: MSiO₃. One exceptionally massive zone within a high-Si/O Cr-silicate arc shows stoichiometry very close to that of pyroxene. We infer that the Cr-silicate arcs may have originated as metastable CrO-rich counterparts of forsteritic olivine and enstatitic-diopsidic pyroxene. Their nucleation as distinct high-Cr phases may have been analogous to nucleation of high-Ca pyroxene in a basalt that had been crystallizing exclusively low-Ca pyroxene. Their breakdown into symplectites may have been analogous to the breakdown of pyroxferroite observed in lunar and martian basalts.

Our observation of plagioclase in the reaction zones around a few of the LEW 88774 cm's (Fig. 1) is the first well-documented occurrence of autochthonous feldspar within monomict ureilites. Average An ratio is 73, and the range among 22 good analyses is 56-85. The compositions feature remarkably high CrO, averaging 0.65 wt%. K₂O contents are consistently low, averaging 0.015 wt%; resembling plag from polymict ureilites [8] more than the exotic, distinctively K-rich plag in the monomict EET96001 [9].

One of the plag-bearing cm reaction zones also contains tiny (~5 μm) equant grains, or globules, of a silica phase (96 wt% SiO₂, 2.4 wt% Al₂O₃). The glasses themselves are remarkably felsic, with consistently close to 70 wt% SiO₂ and 18 wt% Al₂O₃; similar to the glasses, mostly cm-associated, in NWA 766, and to glasses found in FeO-rich ureilite As-881931 [10]. Glasses in FeO-rich ureilites Y-74123 and Y-790981 are even more silicic [11].

The occurrence in peridotites of such silicic glasses, along with Cr-silicates, represents a paradox

and an enigma. The rare occurrence of comparably silicic glasses in terrestrial mantle xenoliths has led to considerable debate. Draper and Green [12] argued the high-silica compositions to reflect low-degree, low- P partial melting of exceptionally high-alkali peridotites, as alkalis at low P act to reduce the activity of silica. The same effect probably was a factor in the ureilites. However, the ureilites experienced moderate-high degree melting, sufficient to virtually purge them of feldspar; and the average ureilite silicic glass has much lower total alkalis, $\text{Na}_2\text{O} + \text{K}_2\text{O}$ (~ 4 wt% vs. ~ 10 wt%), than the terrestrial silicic glasses. Ikeda [10] briefly suggested that high glass SiO_2 contents might reflect Si addition “from nearby metal-sulfide melt.” But his model does not explain, inter alia, what would have caused metallic Si to oxidize to SiO_2 .

Goodrich and Harlow [7; cf. 13] interpreted LEW 88774 as a heteradcumulate, and its Cr-silicates as products of reaction (possibly a form of >3 GPa shock metamorphism) between cm and an opx-saturated residual pore liquid. Citing a lack of Cr loss from the cm's, these authors assumed the Cr-silicates formed prior to the DR episode. However, our studies show extensive Cr loss from some corners of most cm's. Excluding small, secondary (post-DR) grains, Cr_2O_3 in cm ranges all the way from 63 wt% down to 22 wt%. Moreover, the low-Si/O form of Cr-silicate grew as mantles over reduced (and distinctively CrO-rich) olivines. We conclude that the Cr-silicates formed after the DR episode; and the associated silicic glasses also formed, or at least underwent major modification, after the DR episode.

As a model for origin of the SiO_2 - and Al_2O_3 -rich glasses, we suggest that the starting material was a ferroan (Fo75, in the case of LEW 88774) peridotitic restite with a few per cent of roughly basaltic melt. Owing to the relatively moderate $f\text{O}_2$, by ureilite standards, much of the Cr was Cr^{3+} , in cm. After the sudden pressure drop (with concomitant cooling rate increase), a particularly complex form of DR occurred in these ferroan ureilites. As with most ureilites, DR consisted mainly of removal of O from olivine rims, plus melt, to combine with C and form CO_x gas. Early in the DR, the outer portions of cm grains also lost FeO, giving them “reduced” (high) mg ; only later, after nearly all of the cm had acquired high mg , did reduction of Cr^{3+} begin to show appreciable effects, locally, on the cm Cr/(Cr+Al) ratios. One of the earliest effects of DR was a near-total reduction of the melt's FeO into Fe-metal. Secondarily, the melt's drive to equilibrate to low mg in the presence of ferroan pyroxene (surviving from the pre-DR restite), may have caused most of its MgO to partition into the mafic silicates. If so, then the final glass composition is essen-

tially a basalt with near-total depletion of its FeO+MgO. Assuming a suitably ferroan, cotectic (pl-saturated) basalt composition for the pre-DR melt, e.g., taking the EETA 79001B martian basalt as an analog, this model yields a good fit to the observed SiO_2 - and Al_2O_3 -rich glasses typical of ferroan ureilites. Another factor promoting survival of these glass compositions would be high viscosities.

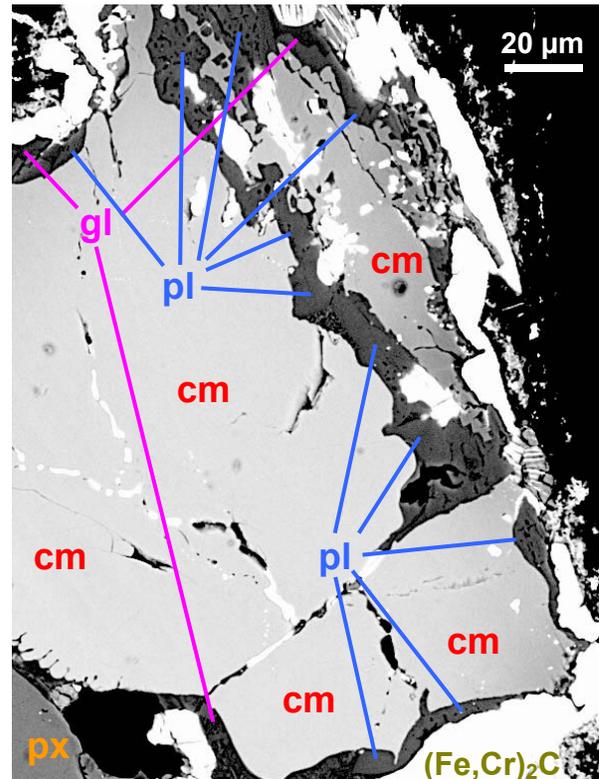


Fig. 1. BSE image of feldspar-rich area of LEW 88774,5. Unlabeled white is mostly Fe,Cr-sulfide.

The concentration of the melt (glasses) near the cm's is another enigma. Possibly the replacement of Cr_2O_3 (reduced to CrO) by Al_2O_3 set up a diffusion gradient that made the local melts particularly enriched Al_2O_3 ; and the resultant especially high viscosity favored survival of these melts.

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