FERROAN ANORTHOSITE: A WIDESPREAD AND DISTINCTIVE, HIGH-OLIVINE/PYROXENE, LUNAR ROCK TYPE

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The title of this work is an homage to Dowty et al. [1]. Between that seminal work and [2], the distinctiveness of ferroan anorthosite (FA) was noted in terms of it being (a) a compositionally “pristine” lunar rock type, (b) uniquely plagioclase-rich (potentially buoyant) among decently sampled pristine rocks, with (c) low mg (≡ molar MgO/[MgO+FeO]) despite (c1) low-sodium plagioclase, (c2) low REE (etc.), and (c3) distinctive ratios of plagiophile element pairs such as Eu/Al and Ga/Al. Another noteworthy but complex, hard-to-constrain [3] trait is (d) uncommonly ancient crystallization ages. If any lunar rock type formed as flotation crust over a primordial magma ocean, FA is surely the leading candidate. Another important and distinctive FA trait (c4), high olivine/pyroxene ratio despite low mg, has until now, with added constraint from some new meteorites, gone rather underappreciated.

In low-pressure, moderate-mg basaltic crystallization, olivine tends to precede pyroxene [4]. Olivine commonly becomes mantled by orthopyroxene, as happened at a late (probably post-flotation) stage in the crystallization of FA 62237 (Fig. 1). In a different way, the few “large” samples of the Mg-suite (i.e., essentially all of the lunar highland cumulate rocks other than FA) also show a systematic olvn-px relationship. Of the 10 with estimated mass >10 grams, 3 have vastly more olivine than px combined with bulk (literature-average) mg in the range 86-87.2, the other 7 have px as their only mafic silicate and bulk mg in the range 67-82 [5]. This step function distribution is consistent with early, magnesian olivine giving way to late, relatively ferroan pyroxene. If we hazard to extend the database with four samples with mass between 3 and 10 g, this picture does not change much; olivine-dominated samples have mg no lower than 83.2, with one exception at 73.3 mol%; the “feldspathic lherzolite” 67667 – a breccia with no Eu anomaly that possibly is a limited “ortho”-cumulate.

The picture changes radically if FA are added. Despite bulk mg in the range 50-63.3, of the four FA samples that are both large (57-1800 g) and relatively mafic-rich, 60025, 62275, 62237 and 62236, three contain more olivine than px. Even the exception, 62236, contains significant (4 vol%) olivine. If we hazard to extend the database with the next most massive of the relatively mafic-rich FA (64435c, ~6 g [6]) the story changes only in detail. In short, the FA (at least those FA relatively rich in mafic silicates) contain far more olivine than px, despite having mg much lower than the ratio at which the Mg-suite cumulates the mafic silicates transition from olivine to px.

Recently, a few anorthosites have turned up among lunar meteorites: Gadamis 004, Ghadduwah 001, Northwest Africa (NWA) 12965 and NWA 13907, all described in the Met. Bull. by Carl Agee. Although (despite the fact that) they are unlikely to all be pristine, all four are thoroughly FA in their mineral chemistry, with low-Na plagioclase and implied bulk mg in the range ~ 61-64 mol%. All are also said to contain olivine, mentioned first (before px) in all four cases. Even assuming these rocks are not pristine, we can still evaluate as unlikely a hypothetical scenario of origin by mixing between an olivine-free FA and olivine-bearing Mg-suite material. If the starting pristine FA is assumed to have had mg not vastly lower than known FA, then unless the admixed olivine had mg far lower than the observed range (83-87 mol%) among olivine-rich Mg-suite cumulates, given the observed (61-64 mol%) mg, the final olivine/px ratio should not be nearly as high as 1 (space does not permit detailed discussion here of the mass balance).

Implications: These olivine/pyroxene-mg relationships strengthen the evidence for FA being “distinctive” [1]. The moderate-high olivine/px ratios of the FA are also hard to explain except by formation of FA as a series of cumulates that buoyantly accumulated toward the top of a magma so immense that it spanned a significant range in pressure. In a magma with convection working toward an adiabatic T-depth gradient, crystallization occurs both shallow (at low T) and deep (at high pressure P). The phase equilibria [e.g., 4] imply that a few kbar of P displaces the olivine/px stability boundary such that the same magma that forms px deep may form olivine shallow. The FA may be blends of floated cumulus plagioclase, originally (pre-accumulation) deep-formed cumulus px, and shallow-formed cumulus olivine, along with additions (Fig. 1) from trapped liquid and (shallow) “adcumulus growth”.