PLAGIOCLASE IRON CONTENT VARIANCE: A SIGNIFICANT COMPLICATION FOR EFFORTS TO IDENTIFY LUNAR TERRAINS OF EXTREMELY HIGH PLAGIOCLASE ABUNDANCE. Paul H. Warren[1] and Randy L. Korotev[2], [1]Earth, Planetary & Space Science, UCLA, Los Angeles, CA 90095, pwarren@ucla.edu, [2]Earth & Planetary Science, Washington Univ. St. Louis, MO 63130, korotev@wustl.edu.

On the basis of reflectance spectroscopy, numerous locales have been identified where the lunar surface material reportedly contains a remarkably high abundance of plagioclase. Ohtake et al. [1] and Yamamoto et al. [2] reported many locales as being "PAN" (purest anorthosite, ≥98% plag). Donaldson Hanna et al. [3] identified many additional locales as "pure crystalline plagioclase" (≥99% plag). So widespread are these locales that [2] suggested that most of the lunar crust is PAN, and [3] inferred "an extensive zone of highly pure (≥99% plagioclase) … anorthositic crust" associated with "most of the nearside and farside multiring and peak ring basins." Such inferences have profound implications for the bulk composition of the lunar crust, for the gross evolution of the Moon, for the "magma ocean" process that hypothetically produced the initial crust by buoyant flotation of anorthosite [4], and even for the bulk composition of the Moon [5].

In a paper in press [5] we urge caution regarding the PAN and "pure crystalline plagioclase" claims. There is little reason to doubt that the locales in question feature relatively low mafic abundances. But just how low, quantitatively, is for various reasons [5] not so clear. One reason is the issue addressed in this work: plagioclase FeO content variability.

The extreme-high plagioclase abundance is inferred based on comparison between iron absorption band strengths in plagioclase (about 1250 nm) versus mafic silicate (about 1000 nm). An underlying assumption is that plagioclase FeO content (Pl-FeO) variance is inconsequentially mild among lunar highland rock materials. Pl-FeO, up to about 0.4 wt% FeO, shows an approximately linear correlation with the depth of the 1250 nm absorption band [6]. Our survey of literature data, augmented by some new UCLA EPMA data, suggests that Pl-FeO variance is not negligible, because Pl-FeO is often far higher in fast-cooled impact melt rocks such as 68415 than it is in the slow-cooled plutonic rock types that probably constitute most of the interior of the lunar crust.

Iron content of plagioclase in plutonic-cumulate lunar rock types has been carefully studied by Hansen et al. [7] and McGee [8]. These studies found average Pl-FeO to be 0.085 wt% in a set of 6 ferroan anorthosites plus 3 Mg-suite plutonic rocks [7], and 0.112 wt% in a set of 16 ferroan anorthosites [8]. The overall average is conveniently about 0.10 wt%.

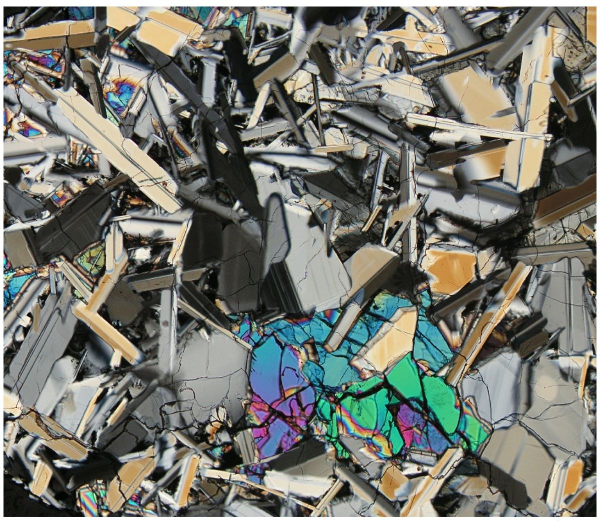
The most revealing example of a highland impact-melt rock with high overall Pl-FeO is Apollo 16 sample 68415. The texture of 68415 is holocrystalline, fine- to medium-grained (rare exceptionally large plagioclase laths up to 3 mm long) and broadly subophitic; sort of a "classic" lunar impact-melt texture. Its mode is 79 vol% plagioclase, 19 vol% mafic silicates, mostly pigeonite pyroxene [9]. Helz and Appleman [9] observed that a minor component, 2-5 vol% of the rock, is a distinctively anhedral and mostly untwinned variety of plagioclase, of evident "xenocrystic" or relict origin. They further noted that Pl-FeO tends to be much lower, even at similar Ab content, in the anhedral plagioclase than in the more common melt-derived lathy plagioclase. The overall Pl-FeO of 68415, based on weighted averaging (~3.5/79) of 19 analyses of the anhedral type and 28 of the lathy type, is 0.39 wt% (this average includes a few additional literature analyses [10, 11] and excludes 20 analyses from [9] that targeted grain cores only).

It has been conjectured that 68415, a type 3 in the impact-melt compositional classification of [12], might be a piece of ejecta from the Orientale impact [13, 14]. At any rate, the preponderance of lathy grain shapes suggests moderately rapid cooling. Impact-melt rocks are in general fast-cooled compared to the plutonic rock types, such as ferroan anorthosite, which are believed to constitute most of the lunar crust. Cooling rate strongly influences the partitioning of iron between plagioclase and other phases. Due either to a kinetic effect of differing extents of melt undercooling [15], and/or to near-solidus and subsolidus exsolution [16], plutonic lunar plagioclase tends to hold far less FeO than expected from equilibrium igneous petrogenesis; cf. [17]. As one indication of the importance of subsolidus effects, among Apollo 16 ferroan anorthosites, those that are virtually pure plagioclase typically have bulk FeO [Korotev, Wash. Univ. INAA data compilation] far higher than the ~ 0.1 wt% level suggested by clean-spot EPMA plagioclase analyses.

We have studied another type 3 [12] sample, rocklet 67514,22 (classification based on UCLA INAA results of 8.7 µg/g Sc, 3.5 µg/g Sm). In mode and texture (Fig. 1) this rocklet is similar to 68415. We also find (UCLA EPMA results) that average Pl-FeO is 0.28 wt%, based on 20 random analyses. The average Pl-FeO for the two type 3 samples, giving extra weight to the much larger 68415, is about 0.35 wt% — 3.5 times higher than the average Pl-FeO for highland plutonic rocks.

Another Apollo 16 rocklet studied at UCLA, 67944,29, which has an extremely fine-grained and mildly poikilitic texture (Fig. 2), is of type 2DB [12] composition (UCLA INAA: 11.8 µg/g Sc, 12.5 µg/g Sm). We find that average Pl-FeO is 0.32 wt%, based on 19 random analyses.

Literature data indicate that some other impact-melt breccias also have high average Pl-FeO. In type 2DB sample 65779, literature (various) data provide 14 Pl-FeO analyses that range from 0.15-0.37 and average 0.26 wt%. For the otherwise little-studied sample 67769, which has a fine-grained poikilitic texture, an admittedly meagre sampling of 9 analyses [18] range from 0.17 to 0.82 wt% and average 0.40 wt%.



0.1 mm 67514,22/37

Fig. 1. Polarized-light microscopic view of Apollo 16 rocklet 67514,22. This compositional type 3 impact melt breccia has a mode and texture, and average Pl-FeO, similar to those of the type 3 large rock 68415.

In summary, many highland impact melt rocks have plagioclase FeO (Pl-FeO) contents higher by large factors (2.6-4) than the Pl-FeO, ~0.10 wt%, that is typical of highland plutonic rocks. Some of the sites identified as PAN (≥98 vol% plagioclase [1]) or even "pure crystalline plagioclase" (≥ 99 vol% plagioclase [3]) on the basis of the (relative) strength of the 1250 nm band from iron in plagioclase, may instead be places where the surface materials are rich in 68415-like, anorthositic, but not PAN-composition, impact melt rocks. Estimation of plagioclase FeO content strictly from spectral characteristics [6] is hardly feasible. Does a relatively deep band depth reflect abundant plagioclase, or plagioclase relatively rich in FeO? The situation is further complicated because "increasing FeO content in plagioclase and coarsening the grain size have similar effects" [19]. The olivine/pyroxene ratio among the mafic silicates is another complication. Absent tight constraints on the mineral-by-mineral hosting of FeO, the spectral reflectance technique is a problematic basis for studying the anorthositic extreme of lunar crustal composition.

The Apollo sample collection is a legacy that continues to greatly benefit planetary science, including as a source for ground truth pertinent to validating results for recent and ongoing remote sensing missions.

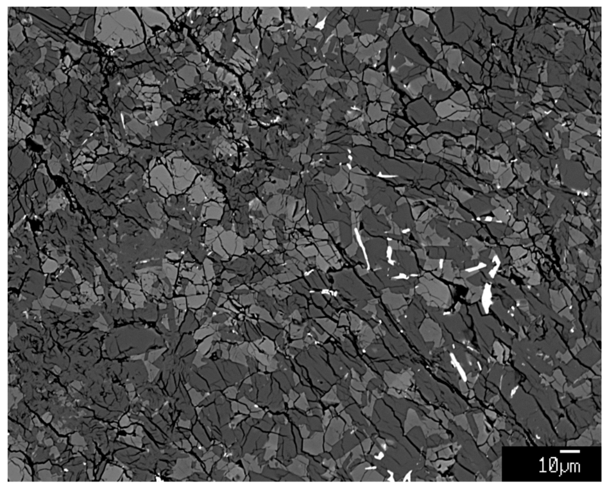


Fig. 2. Backscattered-electron image of Apollo 16 compositional type 2DB impact melt breccia 67944,29. Dark grey phase is plagioclase. The rest of the rock (medium grey shades) is mostly olivine and pyroxene.

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