OLIVINE IN LUNAR DUNITE 72415, A RATHER SHALLOW-ORIGIN CUMULATE.

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Early studies of dunite 72415 and its sister fragments lead to the conclusion that the sample was the brecciated relic of a deep-seated plutonic cumulate, formed during a primordial differentiation [1,2,3]. Further, it was proposed that troctolite 76535 could be related to it by fractional crystallization of a common magma. The present study shows that 72415 is probably neither deep-plutonic nor closely related to 76535.

Dymek et al. [2] stated that 72415 olivine has a "very restricted range in composition (Fo 86-89)" with no systematic variation, and that minor elements are like those in other plutonic rocks. In reality however, the range of Fo 86-89 also shown in [4], is a) wider than expected from analytical error for a single composition b) wider than that analyzed for 76535 in the same study and c) apparently wider than the range in single terrestrial plutonic samples. Also, the calcium content (0.13 % CaO) appears high. The present study of detailed microprobe analyses of 72415 olivines was undertaken to 1) evaluate the reality of the olivine compositional range and how it varies within the sample 2) analyze precisely for CaO as a constraint on petrogenesis 3) compare with terrestrial and other plutonic olivines and constrain the origin of 72415.

Major element variation was determined by analyses for FeO in the dunite and other olivines (Fig. 1), avoiding symplectites and other inclusions. The total range for the dunite is much wider than for replicate analyses on Marjalahti, hence is real, and for multiple point analyses of Stillwater (ultramafic zone) olivines. The variation is not random: the two largest grains in the thin section (5 mm and 2 mm across) are continuously zoned by 1.6% FeO (almost 2 mol % Fo) and 1.1% FeO ($\sim$1 mol % Fo) respectively; the latter shows an abrupt transition in one place from 11.7% to 11.2% FeO (Fig. 2). Terrestrial deep plutonic olivines are zoned only at their outer rims or where in subsolidus reaction with chromite; neither is the case for 72415. (The range reported here is not as wide as measured by [2] for 72415 and 72417 combined; it is possible that 72417 is on average more Fe-rich than 72415). Not only did these 72415 olivines crystallize too fast to maintain equilibrium with the magma, but they then cooled at subsolidus temperature too fast to equilibrate by interdiffusion. Diffusion data for major elements in olivine [5] as used by [6] show that these Mg-Fe gradients would have been eliminated if they had been held at 1100° C

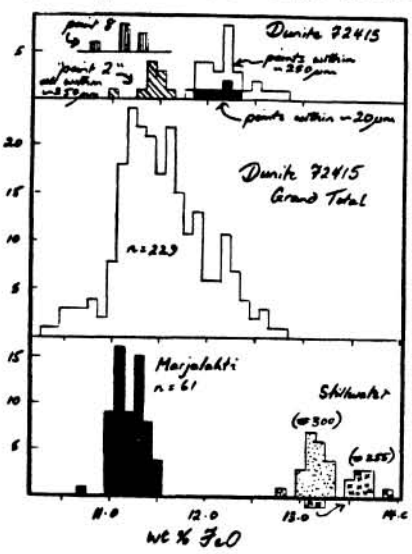


Figure 1. Comparison of dispersion of analyses of FeO in olivines. All analyses were made under similar conditions: 15 Kv; 0.08 microamps; 40 secs peak counts, 2 x 8 secs backgrounds; Si, Mg analyzed simultaneously; Bence - Albee corrections; ARL probe (Univ. Munster).
Marjalahti: analyses are essentially equivalent to analytical variations for a single spot, as the same small area on a small grain was used. The analyses comprise determinations made on about 10 different days, with up to 3 restandardizations/day.
Stillwater: 2 separate samples (supplied by I. McCallum). For each, several different grains, of different sizes, and of cores and rims, were analyzed. For each, the total range is about equivalent to that of Marjalahti i.e. no detected variation within a sample at all. This is confirmed by F-tests on the sample variances.
Dunite 72415: 1 thin section. The total range is wide, and similar to that reported by [2]. The range for single or proximal points (examples shown), repeated analyses on separate days, are consistent with Marjalahti. An F-test on sample variances confirms that the dunite olivines come from a population with much higher variance than multiple analyses on single spots.

Figure 2. FeO wt.% of points in a 2 mm grain in 72415.

for ∿ 2,000 years or at 1000° C for ∿ 5,000 years, at $fO_2 = 10^{-14}$. The cooling times required to maintain the zoning are far too short for a deep plutonic origin.

Calcium analyses show a real and wide spread (Fig. 3), and the variation is large over distances as small as 50 μm. They are much wider than variations in replicate analyses of Marjalahti (Fig. 4), and do not appear to be caused by secondary fluorescence of inclusions. The CaO abundances are higher than in Marjalahti, 76535, and olivines for the Stillwater - Skaergaard intrusions (for a given Fo content), but lower than in olivines from rapidly-cooled rocks such as mare basalts (0.2 - 0.5% CaO) and impact melts (0.15 - 0.3% CaO). They are similar to olivines in terrestrial mantle xenoliths (0.07% CaO) but a lunar mantle origin is precluded on Mg/Fe zoning alone.

The amount of Mg/Fe zoning and the CaO contents in 72415 olivines are consistent with a shallow (hypabyssal) origin rather than a deep-seated plutonic origin. Neither feature can be attributed to the later shock events which affected the rock. Even if 72415 were impact-excavated during deep plutonic formation, it should not have Mg/Fe zoning. In contrast, the lack of Mg/Fe zoning and the low CaO contents of 76535 olivines [2, 7] are consistent with a deep plutonic origin, hence 72415 and 76535 are not closely related. A shallow origin is easier to reconcile with the old age of 72415 (4.45 b.y., new decay constants [1]) than is a deep plutonic origin, but still leaves open the question of how early magnesian magmas were produced, unless an early chilled crust was partially preserved. The ramifications are manifold but only partly explored.

Figure 3. CaO v. FeO wt% for olivines in dunite 72415. Crosses denote analyses with CaO precision (indicated errors are ∿3 sigma on counts) less than the black dots (CaO ± 0.003%), which average 2 or more analyses of longer count times on peak and background and a higher beam current. Open circles are single-point "precise" analyses; the line joins two points a few microns apart and demonstrates local CaO heterogeneities. A trend to increasing CaO with increasing FeO is faintly discernible; if real it is very steep.

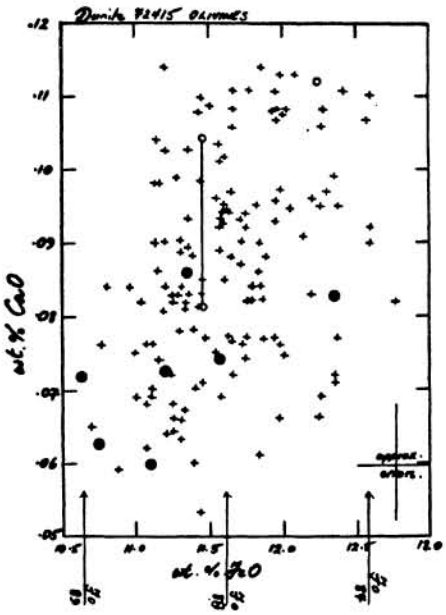
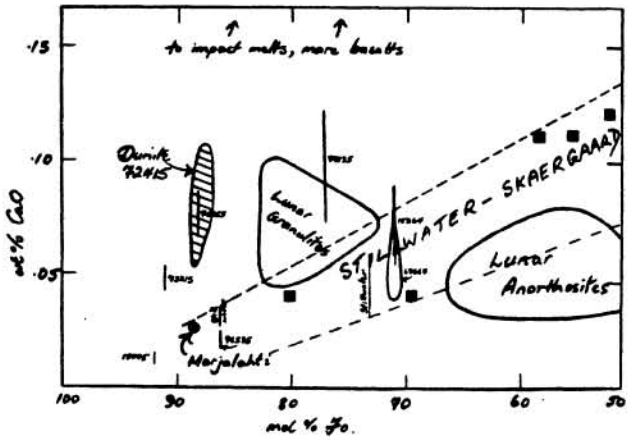


Figure 4. CaO wt% v. Fo for dunite 72415 olivines and others for comparison. Olivines in dunite 72415 have higher CaO for their Fo contents than do terrestrial plutonic olivines (Skaergaard, black squares from [7]; Stillwater, this study). They are much higher than lunar anorthosite olivines (which on this basis might be the slowest - cooled igneous olivines known). However, they fall well below the field for extrusive rocks (0.15% CaO and higher). 76535 and 15445 troctolites lie on the terrestrial plutonic trend, as does Marjalahti (data this study). (Data for granulites, numbered rocks, and lunar anorthosites from [8] and this study).



References

[1] Papanastassiou D.A. and Wasserburg G.J. (1975) Proc. Lunar Sci. Conf. 6th, 1467-1489. [2] Dymek R.F. et al. (1975) Proc. Lunar Sci. Conf. 6th, 301-341. [3] Lauer, J.C. and Schmitt R.A. (1975) Proc. Lunar Sci. Conf. 6th, 1231-1254. [4] Bell P.M. et al. (1975) Proc. Lunar Sci. Conf. 6th, 231-248. [5] Buening D.K. and Buseck P.R. (1973) Jour. Geophys. Res. 78, 6852-6862. [6] Freer R. (1981) Contrib. Min. Pet. 76, 440-454. [7] Nwe Y.Y. (1976) Contrib. Min. Pet. 55, 105-126. [8] Smith J.V. et al. (1980) Proc. Lunar Planet. Sci. Conf. 11th, 555-569.