DUNITE FROM THE LUNAR HIGHLANDS: PETROGRAPHY, DEFORMATIONAL HISTORY, Rb-Sr AGE

A.L.Albee,A.A.Chodos,R.F.Dymek,A.J.Gancarz,D.S.Goldman,D.A.Papanastassiou, and G.J.Wasserburg; Lunatic Asylum; Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, Ca. 91109, Contribution No. 2442

Five fragments of highly-crushed dunite (72415 to 72418) were collected at Apollo 17 Station 2 from a single 10x20cm clast in Boulder #2, which is a metaclastic blue-grey breccia (72435). It is logical to expect a lunar dunite to provide some insight into the composition of the lunar mantle, the origin of the ANT-rock suite, and possibly the character of primitive crustal-differentiation processes. Such insights are complicated by the complex history of deformation undergone by this sample. However, despite the complex history, Rb and Sr appear to have remained undisturbed and this rock is inferred to be a product of primary lunar differentiation.

Rounded clasts composed of large (to 10mm),single crystals of pale-green, translucent olivine are enclosed in a granular, white matrix composed predominantly of olivine. The matrix formed simply by crushing without recrystallization and has the same composition (Fo_{86-89}) as the olivine clasts. Other minerals, which include plagioclase, Cr-spinel, high- and low-Ca pyroxene, and Fe-metal, occur as clasts within the matrix and included within the olivine clasts. In both cases the habit of each of these minerals is similar.

Large, single olivine crystals have pronounced undulatory extinction and planar partings resulting in a mosaic of rhomb-shaped domains bounded by partings or strain-bands. Small ($\sim$50μm) oval or equant olivine grains, with relatively uniform extinction, are aligned along some of these strain-bands. Some of the planar partings appear to be decorated with minute beads, which are apparently Fe-metal, and some terminate in a string of Fe-metal beads. Most of the clasts are single olivine grains. However, zones of symplectic intergrowths, and rarely, aggregates of plagioclase laths associated with pyroxene granules, occur within the clasts. These zones are interpreted as relic grain boundaries and as primary crystallization features. Similar aggregates of plagioclase laths (An_{88-92}) and pyroxene granules also occur as broken fragments within the matrix. Olivine is dusted with tiny ($<$1μm) inclusions, which appear to be predominantly Fe-metal in some areas and predominantly spinel in other areas. Cr-spinel also occurs in olivine as discrete inclusions (up to 25 μm).

Symplectic intergrowths of Cr-spinel+high Ca pyroxene$\pm$low Ca pyroxene $\pm$ plagioclase $\pm$ Fe-metal occur as tiny, ovoid inclusions in olivine, along relic grain boundaries, and as broken fragments within the granulated matrix. Felty aggregates of shocked and recrystallized plagioclase (An_{94-97}) with minor pyroxene also occur as ovoid inclusions within the olivine clasts and as broken fragments in the matrix.

Table 1 gives the mode, "average" phase compositions, and calculated bulk-chemical composition of thin-sections 72415,11 and 72415,12. The phases are relatively uniform in composition, but plagioclase is slightly more sodic in the laths than in the felty aggregates and spinel is slightly more Cr-rich in inclusions than in the symplectic intergrowths. Olivine is low in Ca and Mn and exceptionally low in Cr. Rare grains of troilite and whitlockite associated with Fe-metal and of Zr-Cr armalcolite were identified. Fe-metal contains 1.3 to 2.2 wt. % Co and has an exceptionally high Ni content (24.5 to 31.8 wt. %), perhaps indicative of the primary origin of the metal and the primitive nature of the dunite.

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Table 1. 72415,11 and 72415,12 Phase abundances, "average" phase compositions and bulk-chemical composition

	Olivine	Plagioclase	Low-Ca pyroxene	High-Ca pyroxene	Fe-metal*	Spinel	Bulk composition
Vol.%	91.4±2.2	4.03±0.45	3.06±0.40	1.33±0.26	0.10±0.07	0.10±0.07	(1962 points)
Wt. %	91.85	3.55	3.08	1.34	0.24	0.14	
SiO_2	40.09	44.79	51.26	52.71	0.04	0.19	40.6_1
Al_2O_3	<0.01	35.00	1.07	2.73	n.a.	19.95	1.2_7
Cr_2O_3	<0.01	n.a.	0.84	0.85	0.36	48.28	0.1_1
TiO_2	<0.01	<0.01	0.31	0.54	<0.01	0.49	0.0_2
MgO	48.12	0.23	33.72	18.61	1.31	11.10	45.5_1
FeO	11.90	0.14	8.11	3.00	67.07	18.64	11.4_6
MnO	0.11	n.a.	0.11	0.13	0.06	0.75	0.1_1
CaO	0.13	19.25	5.55	21.28	<0.01	n.a.	1.2_2
Na_2O	n.a.	0.62	<0.01	0.05	n.a.	n.a.	0.0_2
K_2O	n.a.	0.09	n.a.	n.a.	n.a.	n.a.	$<0.0_1$
BaO	n.a.	0.04	n.a.	n.a.	n a.	n.a.	$<0.0_1$
ZrO_2	n.a.	n.a.	n.a.	n.a.	n.a.	0.08	$<0.0_1$
V_2O_3	n.a.	n.a.	n.a.	n.a	n.a.	0.35	$<0.0_1$
NiO	0.04	n.a.	n.a.	n.a.	29.67	n.a.	0.1_3
Co	n.a.	n.a.	n.a.	n.a.	1.46	n.a.	$<0.0_1$
Total	100.39	100.16	100.97	99.90	100.01	99.83	100.46
	Fo 88	An 92	En 81	En 54			$\bar{\rho}$ =3.30
	Fa 12	Ab 5	Fs 11	Fs 5			
		Or 1	Wo 8	Wo 41			
		Others 2					

*Element abundances: converted to oxides for bulk-composition calculation

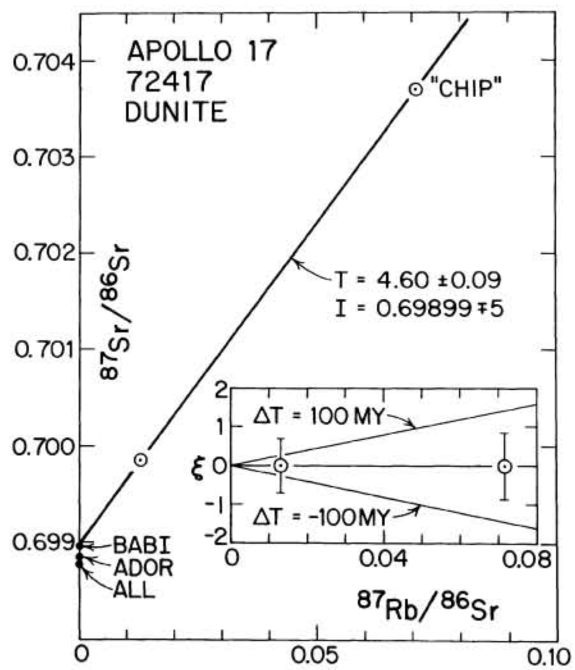
n.a. = not analyzed

TABLE 2 : TRACE ELEMENT & ISOTOPIC DATA

	Sym.I[c]	TR chip[d]	TR[d]	L[e]
wt(g)	0.125	0.20	2.0	-
K(ppm)	29.1	7.30	21	.26
Ba(ppm)	5	1.2	4	.09
Rb[a]	0.0843	0.0830	0.088	.72
^{88}Sr[a]	15.08	2.712	11	.07
$^{87}Rb/^{86}Sr$[b]	1.304	7.14	-	-
$^{87}Sr/^{86}Sr$	.69985±5	.70370±6	-	-

a: 10^{-8} mole/g; b: x10^2; c: Symplectic intergrowths; d: TR- Total rock; e: L-Fraction leached from total rock(col.4)

Figure: Rb-Sr evolution diagram for dunite 72417. Insert indicates the effect on age of uncertainties ξ (in parts in 10^4) of $^{87}Sr/^{86}Sr$. Sample enriched in symplectic intergrowths has the low Rb/Sr. Initial Sr is equal to BABI and distinctly higher than ADOR (Angra dos Reis) and ALL (Allende [2]).



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It is important, although difficult, to distinguish between the primary and the deformational features of this dunite breccia. We infer that the primary dunite consisted of about 95% coarse-grained (to at least 10 mm) olivine crystals containing spinel inclusions and melt inclusions, which probably had crystallized to plagioclase+pyroxene and spinel+plagioclase+pyroxene prior to the shock deformation. Interstitial to the coarse olivine grains were aggregates of spinel+pyroxene+plagioclase+Fe-metal, partly as symplectic intergrowths. The coarse grain-size, the symplectic intergrowths and the compositions of the phases suggest that this rock did not form as a near-surface cumulate. Subsequently, the dunite was excavated from depth by a cratering event and subjected to shock pressures in the range of 350 to 450 kb, resulting in the deformational and recrystallization features observed in the rounded olivine clasts. The rock was crushed at low shock-pressures, probably prior to its incorporation into the blue-grey matrix breccia as a clast, as there is no evident admixture of blue-grey matrix breccia material to the dunite.

Isotopic and trace element analyses were done on selected materials from sample 72417, which include a small "total rock chip", a 2g total rock, and hand-picked fragments rich in simplistic intergrowths (table 2). All samples were free of lunar exterior surfaces and were cleaned of adhering lunar soil. The differences in trace element concentrations between the total rock samples are due to biased sampling. There is considerable depletion of Sr in the small "chip" compared to the other samples. Leaching the total rock in HNO_3+ HCl showed that K and Rb are readily removed.

The figure shows the data points for the "chip" and the symplectic intergrowths, which define a remarkably straight line corresponding to an age of 4.60 AE and initial $^{87}Sr/^{86}Sr$, I=0.69899. Pb isotopic data on the leach of the total rock give a model age of 4.48 AE which is significantly younger [1]. If the Rb-Sr data represent a true internal isochron, then this dunite must be one of the earliest lunar differentiates. The value of I is low enough to be compatible with such an interpretation. A value greater than BABI would render this interpretation questionable. Because of the complex nature of this rock and the low trace element concentrations these results must be confirmed. The low laboratory blank levels have no significant effect on the Rb-Sr data. It is possible that the trace element concentrations, the isotopic compositions, and consequently the age result from the addition of extraneous lunar materials during the complex history of the dunite. Such materials include the matrix of the enclosing K-rich breccia (72435), clasts of anorthositic rocks, and lunar soil. However, the small "total rock chip", which critically controls the age, has K/Rb much less than any of these contaminants and less than mare basalts. Therefore, the possibility of contamination by these materials may be excluded. This is also true for the 2g total rock and the symplectic intergrowths, with regard to the high Rb/Sr contaminants. As there is no evidence for contamination from either petrographic or trace element data, we tentatively conclude that this rock must represent a very early differentiate, derived from the upper lunar mantle. This rock is so depleted in trace elements (including U and Th) that it cannot represent the source reservoirs from which younger basaltic magmas were derived. This rock must represent a cumulate formed during early lunar differentiation and associated differential gravitational settling.

[1] F. Tera et al., this volume.
[2] C. M. Gray et al., (1973) Icarus 20, 213