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A MONAZITE-BEARING CLAST IN APOLLO 17 MELT BRECCIA.

BRADLEY L. JOLLIFF, DEPARTMENT OF EARTH AND PLANETARY SCIENCES & MCDONNELL CENTER FOR THE SPACE SCIENCES, WASHINGTON UNIVERSITY, ST. LOUIS, MO 63130.

A phosphate-rich clast in a pigeonite-plagioclase mineral assemblage occurs in Apollo 17 impact-melt breccia 76503,7025. The clast, measuring 0.9 × 0.4 mm in thin section, contains 3.3% (volume) apatite [$Ca_5P_3O_{12}(F,Cl)$], 0.8% whitlockite [$Ca_{16}(Mg,Fe)_2REE_2P_{14}O_{56}$], and trace monazite [$(LREE)PO_4$]. Major minerals include 26% pigeonite, $En_{53-57}Fs_{34-35}Wo_{8-13}$, and 69% plagioclase, $An_{84-92}Ab_{7-15}Or_{0.6-1.1}$. Troilite, ilmenite, and other accessory minerals constitute <1% of the assemblage and Fe-metal occurs along fractures. Also present in the melt breccia as a separate clast is a fragment of felsite (K,Ba-feldspar, "ternary" plagioclase, and a silica phase - quartz[?]). Based on the association of these clasts and their assemblages, a parent lithology of alkali-anorthositic monzogabbro is postulated. Monazite occurs in the phosphate-bearing clast as two <10 μm grains intergrown with whitlockite. The concentration of combined REE oxides in monazite is 63.5% and the chondrite-normalized REE pattern is strongly enriched in LREE (Figure 1a), similar to lunar monazite in 10047,68 [1] and terrestrial monazite [e.g., 2]. Thorium concentration was not measured in monazite, but based on oxide analyses of ~100% (including interpolated values for REE not measured), substantial Th concentration is not indicated, similar to monazite in 10047,68. Measured monazite/whitlockite REE ratios are La: 11, Ce: 8, Sm: 3.6, Y: 0.9, Yb: 0.5. Compositions of monazite and coexisting whitlockite and apatite are given in Table 1.

Analytical methods. Mineral analyses were done using a JEOL 733 electron microprobe, operating at an accelerating voltage of 15 KeV and a beam current of 30 nA. Synthetic glass standards were used for the REE [3] and natural apatite was used as the standard for P and Ca. Mineral standards were used for other elements in the phosphates and for all elements in the silicates. The data were reduced according to the method of [4].

Petrographic description. The texture of the phosphate-bearing clast is generally subophitic and fractured. Blocky plagioclase laths range in size up to 100 μm and pyroxenes range up to 150 μm. Pigeonites contain very fine exsolution lamellae and the larger crystals contain blocky, prismatic plagioclase inclusions. The forms of apatite crystals range from small, euhedral prisms (narrow, 2 × 30 μm, to squat, 10 × 20 μm) to subhedral, somewhat poikilitic masses up to 80 μm across. Whitlockite occurs as irregular overgrowths and extensions of the large apatite crystals, up to 30 μm in maximum dimension, and as smaller, rare, isolated grains. Monazite is intergrown with whitlockite as small masses of maximum dimension ~8 μm. Textures suggest the following crystallization sequence for the phosphates: apatite → whitlockite → monazite → whitlockite. Early, euhedral apatite, mantled by plagioclase, has relatively high Mg' [atomic Mg/(Mg+Fe)] and Cl concentration, and low REE concentrations. Coarser apatite overgrown by whitlockite has lower Mg', lower Cl concentration, and 2 × higher REE concentrations than early apatite (Table 1). Apatite adjacent a whitlockite overgrowth has the lowest measured Mg' (0.18) and highest REE concentrations (e.g., 0.71 % Ce_2O_3). There is *no* systematic zoning in whitlockite in a traverse from a contact with apatite → monazite inclusion → edge of whitlockite crystal.

Discussion. According to the model developed by [5] based mainly on experimental work by [6], DREE (whit/melt) values of whitlockite in this assemblage are strongly suppressed due to partial saturation of the dominant REE substitution mechanism, ranging from 6-7 for the LREE to 4 for Y (treated as a proxy for Ho) and 2 for Yb. These compare to DREE values 2-4× higher (dependant on Fe/Mg) in whitlockite at low REE concentrations [5,6,7]. As a result, whole-rock DREE (solid/melt) for late-stage crystallizing assemblages having 3-10% whitlockite range from ~0.2 to 0.8, but do not exceed unity, suggesting that the melt concentrations of REE did not decrease once whitlockite began to crystallize, but increased only moderately. If the final residual liquid equilibrated with 0.75% whitlockite (volume % in the assemblage), then a bulk or starting composition (REE) of about 2 × high-K KREEP [8] is sufficient to yield whitlockite of the observed composition. Due to nonsaturating REE substitutions at this concentration level, the whitlockite structure can accommodate REE in excess of 2 atoms per 56 oxygens [5,7], thus it is not necessarily high REE concentration in residual melt that led to monazite saturation. Rather, a decrease in the activity of Ca relative to that of P is suggested as the cause of monazite stability.

The ratios of REE in whitlockite to those in apatite in an REE-rich zone adjacent to a whitlockite crystal are 4.8 (La) and 4.7 (Ce) (Table 2), indicating apatite/melt DREE values of 1.2 and 1.3, respectively, if the apatite and whitlockite are in equilibrium. These compare to values of half that magnitude or less inferred by [5] from coexisting apatite-whitlockite pairs in Apollo 14 samples.

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Table 1. Phosphate compositions in 76503,7025c.

	Apt (1) n=1	Apt (2) n=4	Whit n=8	Monazite n=2
P205	41.92	41.37	42.10	32.21
SiO2	0.35	0.48	0.33	0.18
Al203	na	na	0.04	0.02
FeO	0.71	0.39	1.59	0.45
MnO	0.06	0.04	na	na
MgO	0.23	0.07	2.61	0.32
CaO	54.42	54.66	39.69	3.99 (3)
Na2O	<0.02	0.07	0.02	<0.02
Y203	na	na	3.56	3.08
La203	0.06	0.17	1.24	13.30
Ce203	0.12	0.42	3.36	27.45
Nd203	na	na	2.28	11.97
Sm203	na	na	0.60	2.13
Yb203	na	na	0.16	0.08
Other REE (4)	--	--	[2.2]	[5.5]
F	3.90	3.83	na	na
Cl	0.35	0.17	na	na
oxide sum	102.1	101.7	99.7	100.6
- O = F	1.64	1.61	--	--
- O = Cl	0.08	0.04	--	--
corrected sum	100.4	100.0	99.7	100.6
No. of cations based on following negative charges:	25	25	112	8
Tetrahedral cations				
P	2.98	2.96	13.70	1.00
Si	0.03	0.04	0.13	0.01
Sum (tet)	3.01	3.00	13.83	1.01
Non-tetrahedral cations				
sum REE	0.01	0.02	2.07	0.86
sum others (5)	4.98	5.00	18.39	0.19
Sum non-tet	4.99	5.02	20.45	1.05
Mg/(Fe+Mg)	0.36	0.24	0.75	0.56

na = not analyzed
(1) Fine-grained, euhedral, enclosed in plagioclase, early-forming.
(2) Coarser, subhedral, intergrown with whitlockite, late-forming.
(3) Possibly some contribution from whitlockite.
(4) Other REE by interpolation or extrapolation.
(5) "Others" include Al, Fe, Mn, Mg, Ca, Na.

Table 2. REE ratios.

	Mon/ Whit	Whit/ Apt(1)
Y203	0.9	
La203	10.7	4.8
Ce203	8.2	4.7
Nd203	5.2	
Sm203	3.6	
Yb203	0.5	

(1) Apatite in "REE-rich" zone adjacent contact with whitlockite.

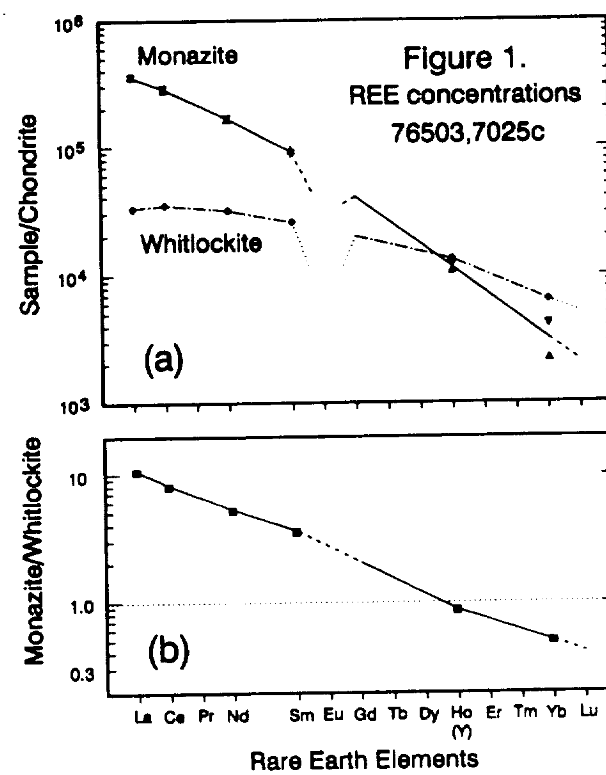

Figure 1.
REE concentrations
76503,7025c