HETEROMORPHISM AND CRYSTALLIZATION PATHS OF KATUNGITES, NAVAJO VOLCANIC FIELD, ARIZONA, USA

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A swarm of thin, isochemical but heteromorphic, lamprophyre (katungite) dikes crops out in the valley of Hasbidito Creek in NE Arizona. The dikes, which are generally well exposed, are part of the mid-Tertiary Navajo volcanic field of the Colorado Plateau. In contrast to the minette dikes of the region, these katungites have produced strong thermal effects on the adjacent Triassic sandstone wallrocks which are commonly baked and bleached at the contacts. It is evident that the katungite dikes were emplaced at higher temperatures and were more volatile-rich than the minettes. The few inclusions in the katungite dikes are crustal in origin.

Whole-rock chemical analyses of samples from four of the dikes indicate that the dikes are chemically identical to the katungites of Uganda originally described by Holmes (1937). Like the Ugandan samples, the Arizona katungites are characterized by extreme silica undersaturation and high concentrations of TiO₂, MgO, CaO, K₂O, and P₂O₅ (Table 1). They are notably enriched in the rare-earth elements, particularly the LREE, and in Ba, U, and Th. Striking characteristics of these isochemical dikes include the wide variability in modal mineralogic compositions (heteromorphism) and the large number of mineral phases present.

We have identified over 20 mineral phases in samples of the Arizona katungites, and as many as 18 phases may occur in a single sample (Table 2). Electron microprobe analyses have been completed on most phases. The major phases are phlogopite (Ph), olivine (Ol), perovskite (Pv), opaque oxides (0x), \pm melilite (Mel), and \pm clino-pyroxene (Cpx). There is an antithetic relationship in the abundances of Mel and Cpx with Mel ranging from 0 to 23% and Cpx from 30 to 0%. Two generations of Cpx can be distinguished; one earlier (ECpx) and one later (LCpx) than the Mel. Minor and trace phases include wollastonite (Wo), nepheline (Ne), apatite (Ap), pectolite (Pe), thomsonite (Th), natrolite (Nat), calcite (Ca), dolomite (Do), tobermorite (To), aenigmatite (Ang), and andradite (Ad). Some of these phases have been identified only in X-ray patterns. The complex and variable mineralogic compositions of these samples reflect both incomplete reactions and differing crystallization histories for individual dikes.

Based upon the modal mineralogies of nine samples of the dikes we recognize four general non-equilibrium assemblages: (1) Ol, Ph, Pv, Ox, ECpx; (2) Ol, Ph, Pv, Ox, Mel; (3) Ol, Ph, Pv, Ox, LCpx; and (4) Ol, Ph, Pv, Ox, Mel, Pe, Th \pm Wo. Comparison of the assemblages with recent experimental results of Arima and Edgar (1983) and Lloyd (1985) shows they represent various combinations of complete and incomplete reactions. Heterogeneous reaction relations were determined by entering the phase compositions determined by electron microprobe into the computer code GENMIX to obtain balanced reactions. A few examples are given below. In all four assemblages Ol and Ox crystallized first at approximately 15 Kb and 1200°C, based upon the 5% H₂O phase diagram of Arima and Edgar (1983). A melt composition based on sample BOL-4-84 (Table 1) with iron as FeO and recalculated to 100% will yield the following reaction (in molar percent):

Melt = 35% O1 + 9% Ox(Titanomagnetite) + 56% liquid 1

Liquid 1 will be higher in Al2O3 and CaO and lower in MgO and FeO than the original melt. The presence of Ph in all assemblages indicates that nearly isobaric crystallization then occurred with the melt moving from the Ol-Ox-liquid(L) field into the ECpx-Ph-Pv-Ox-Ap-L field. The approximate reaction relation here is:

35% Ol + 9% Ox(Titanomagnetite) + 56% liquid 1 = 36% ECpx + 44% Ph + 8% Ox(Titanomagnetite) + 6% Ap + 4% Pv + 2% liquid 2

TABLE 1

MAJOR AND TRACE ELEMENT ANALYSES OF KATUNGITE SAMPLES

	Holmes					
	(1937)	AWL-35-83	BOL-4-84	BOL-8-84	BOL-12-84	BOL-13-84
Si02	35.51	33.58	34.37	34.10	32.77	33.69
Ti02	4.88	4.74	5.16	4.52	4.74	4.30
A1203	6.83	6.84	6.53	6.31	6.27	6.62
Fe ₂ 0 ₃ .	9.68	5.40	5.57	6.33	7.30	5.51
Fe0	2.70	7.56	7.57	6.02	5.07	7.12
Mn0	0.22	0.20	0.20	.20 0.18 0.18		0.20
Mg0	11.67	16.14	16.55	17.80	15.92	15.56
CaO	16.00	14.25	13.92	11.85	12.37	14.23
Na ₂ 0	1.56	1.45	1.16	1.30	1.45	1.42
K20	3.30	3.26	3.06	2.69	1.98	3.54
H20 ⁺	3.11	4.12	3.77	6.74	9.26	4.91
H_0	1.31	0.38	0.27	0.59	0.75	0.26
P205	1.18	1.60	1.52	1.06	1.38	1.70
SrO	0.24	0.23	0.29	0.16	0.18	0.26
S	-	0.21	<0.01	0.16	<0.01	<0.01
Total	100.41*	99.95	99.94	99.80	99.62	99.31
			Trace Elemen	ts (ppm)		
La Ce Nd		164 335 151	182 356 139	136 269 116	157 338 163	178 352 170
Sm Eu Tb Dy Yb		15.6 4.99 2.28 7.11 2.66 0.282	23.7 5.16 1.53 7.36 2.56 0.279	18.2 3.98 1.18 5.68 2.19 0.145	20.4 5.15 1.53 6.14 2.54 0.250	21.6 5.29 2.30 6.80 2.55 0.255
Ba U Cr		1970 5.56 566	2048 5.15	1291 4.09	1904 4.88 -	1854 5.40
Th Rb		20.2 86	21.5 117	16.5 90.1	22.4 97.7	21.5 148

Major Elements (%)

* Includes 1.47% CO2

TABLE 2

MODAL MINERALOGIC COMPOSITION OF KATUNGITE SAMPLES

Mineral	AWL-35-83 %	80L-1B-84 %	80L-2A-84 %	BOL-3-84 %	BOL-4-84 %	80L-8-84 %	BOL-11-84 %	BOL-12-84 %	BOL-13-84 %
Olivine	12	12	12	12	18	6	19	2	16
Phlogopite	30	17	7	35	29	25	39	16	31
Perovskite	7	8	5	7	5	4	4	3	4
Melilite	23	-	3	13	18	-	8	-	3
Clinopyroxene	Tr	30	25	-	Tr	22	1	20	-
Opaque Oxides	7	7	10	- 11	7	5	13	8	9
Wollastonite	2	-	-	-	-	-	-	?	?
K-Feldspar	-	-	-	-	-	-	-	Tr	-
Pectolite	3	-	-	3	-	-	Tr	-	3
Natrolite	-	_	-	-	-	-	-	Tr	-
Thomsonite	1	-	-		-	-	-	· -	-
Andradite	ī	-	-	1	-	-	-		1
Calcite	2	-	2	-	-	1	-	-	Tr
Dolomite	-	-	-	-	-	Tr	-	-	-
Sernentine	Tr	11	13	Tr	-	17	-	17	Tr
Chlorite	Tr		-	-	-	-	-	-	Tr
Homatite	Tr	-	-	-	-	-	-	-	Tr
Tohermorite*	Tr	-	-	-	-	-	-	-	-
Na-Amphihole	-	-	-	-	-	-	-	-	Tr
Aenigmatite*	Tr?	-	-	-	-	-	-	-	-
Anatite	Tr	-	_	-	Tr	1	-	1	Tr
Pyrite	Tr	-	-	-	-	-	-	-	-
Nenheline	-	-	-	-	-	4	-	-	?
Altered Groundma	iss 10	15	23	18	22	15	16	33	33

*Identified only by x-ray diffraction.

Liquid 2 is a high alkali + water-bearing critical fluid. This reaction may have occurred during ponding of the katungite magma at the base of the crust beneath the Colorado Plateau (\sim 43 km depth). Continued crystallization apparently took place along diverging paths. Some portions of the magma moved rapidly to the surface freezing in the ECpx-Ph-Pv-Ox-Ap equilibrium assemblage along with unreacted Ol. In other cases, ascent was slower and the magma moved into the Ol-Mel-Pv-Ap-Ox-L field. Phlogopite apparently did not react at this point although the ECpx reacted with the liquid to form Mel. As pressure and temperature continued to fall, completed reaction (Mel+L+LCpx) and incomplete reaction (Mel+L+Wo+Pe+Th) assemblages developed. Variable amounts of very late serpentinization of Ol occurred in most samples along with very minor chloritization of Ph. A late-stage, interstitial, low-Ti Ad crystallized in some samples.

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