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Feldspar Crystallization Trends in Leucite-Bearing and Related Assemblages

A.K. Ferguson* and A. Cundari
School of Earth Sciences, Department of Geology, University of Melbourne, Parkville 3052, Australia

Abstract. Feldspar chemical variations in representative leucite-bearing and related rocks from well-known localities in Italy, Germany, Uganda and Australia demonstrate that "phenocrystal" core to rim variations may not represent the feldspar crystallization trend in the host lava and only the groundmass feldspar zoning trend is a reliable indicator of crystal-liquid relationships. Textural relationships indicate that coexisting plagioclase and alkali feldspar crystallized sequentially, the latter after the former, rather than cotectically.

Groundmass alkali feldspar show Ca-, Na-depletion and K-enrichment zoning trends. Plagioclase crystallization follows Ca-depletion, Na- and K-enrichment trends. Typically, Sr and Ba solid solubility is significant, particularly in groundmass feldspar.

The alkali feldspar variation trend from groundmass assemblages is not consistent with the theoretical phase relationships in the system $NaAlSiO_4-KAlSiO_4-CaAl_2Si_2O_8-SiO_2$ ("The phonolite pentahedron") proposed by Carmichael et al. (1974).

Factors believed to be important in controlling feldspar crystallization trends are the Sr-Ba feldspar components, the role of the coexisting pyroxene and the presence of F, Cl and/or their alkali compounds.

Introduction

Feldspar crystallization trends in some leucite-bearing lavas of the Roman Region, Italy, show that "both sanidine and plagioclase compositions move toward the Ab apex as crystallization proceeds, since both feldspars became more sodic toward the crystal margins" (Baldridge et al. 1981). Likewise, in rocks of the "shoshonite-banakite series" of Wyoming both calcic plagioclase and sanidine coexisting in the groundmass become more sodic as crystallization proceeds (Nicholls and Carmichael 1969). It is, therefore, perplexing that groundmass alkali feldspar from Roman Region leucite phonolites show K-enrichment and Ca-, Na-depletion trends and coexisting "phenocrystal" alkali feldspar opposing Na and K variation trends, respectively (Cundari 1979). Also, in the Mount Suswa phonolite-trachyte suite of Kenya "... regardless of the direction of zoning in the phenocrysts, the groundmass feldspars of all the lavas are sodic at the cores and become more potassic and less calcic toward the margins" (Nash et al. 1969). Feldspars from trachyte flows in Central Victoria, Australia, show an extreme K-enrichment zoning trend to Or_{60} (Ferguson 1978), exceeding the low temperature minimum in the system $KAlSi_3O_8-NaAlSi_3O_8-CaAl_2Si_2O_8$ at $Or_{37}Ab_{63}$ (Bowen and Tuttle 1950).

This paper is concerned with feldspar crystallization trends in leucite ± nepheline ± sodalite bearing and related assemblages as deduced from the authors' systematic studies of selected lava suites from major (e.g. south-west Ugandan, Roman volcanic regions) and minor (e.g. New South Wales, Australia) occurrences.

It will be demonstrated that feldspar compositional variations from *individual specimens* may not conform to those for the *suite as a whole* and generally show K-enrichment zoning trends for rim and groundmass compositions. Coexisting "phenocrystal" plagioclase and alkali feldspar may not be considered as equilibrium pairs crystallized from the same host liquid composition and *one feldspar* ± feldspathoids characterize the investigated groundmass assemblages.

Parageneses and Specimen Material

The leucite-bearing volcanics from south-west Ugandan and Roman Regions are naturally distinguished in two main series, i.e. a *tephritic series* (modal plagioclase > ca. 15 vol. %) and a *leucitite series* (modal plagioclase < ca. 15 vol.%), which converge at their mafic ends to a third group of basanite compositions, genetically related to the above series (Cundari and Le Maitre 1970; Ferguson and Cundari 1975).

The tephritic series includes mainly leucite-tephrites and their leucite-phonolite variants (defined according to Streckeisen 1967). The essential mineralogical composition of these rocks is clinopyroxene + plagioclase + leucite and variable proportions of alkali feldspar, nepheline, olivine, titanomagnetite, ilmenite, mica, amphibole and andradite-rich garnet. This series forms a large proportion of south-west Ugandan and Roman volcanics as well as significant occurrences in Indonesia (Whitford et al. 1979), Germany (Duda and Schmincke 1978) and Ethiopia (Brown and Carmichael 1969).

The leucitite series includes mafic to ultramafic lavas (mafics > 50% vol.%), characterized by diopside/sahlite, leucite and variable proportions of olivine, phlogopite, K-rich amphibole, titanomagnetite, perovskite, nepheline, sodalite and alkali feldspar. This series is well represented

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* *Current address:* The Broken Hill Proprietary Co. Ltd., 140 Williams Street, Melbourne 3000, Australia

Offprint requests to: A Cundari

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Table 1. Representative chemical analyses and structural formulae of feldspars from south-west Ugandan (C.2799, C.2871) and Roman Region (SB.1) lavas of the tephritic series

% wt.	C.2799				C.2871				SB.1		
	"phenoxl"			"phenoxl"	"phenoxl"				"phenoxl"		
	core	rim	gm	rim	core	rim	gm	gm	core	rim	gm
SiO_2	54.4	55.1	63.0	63.0	52.6	54.9	54.1	53.5	62.8	64.0	63.3
Al_2O_3	27.7	27.3	20.8	20.3	29.6	29.3	28.2	28.0	19.2	18.4	19.1
Fe_2O_3	1.28	0.67	0.48	0.46	0.34	0.22	0.61	0.84	0.25	0.43	0.60
CaO	10.2	9.96	1.50	1.40	11.2	10.2	11.1	11.5	0.25	0.54	0.80
Na_2O	4.58	4.86	4.10	4.53	4.60	5.30	4.53	4.38	1.80	3.10	3.10
K_2O	1.07	1.29	9.60	9.17	0.69	0.87	1.04	0.98	13.6	12.6	12.10
BaO	0.15	0.15	[b]	0.30	[b]	—	0.25	0.11	1.4	0.06	0.11
Σ	99.38	99.33	99.48	99.16	99.03	100.79	99.83	99.31	99.30	99.13	99.11
Cations[a]											
Si	9.930	10.042	11.519	11.569	9.629	9.844	9.847	9.802	11.742	11.850	11.711
Al	5.952	5.875	4.483	4.393	6.387	6.192	6.052	6.040	4.232	4.016	4.166
Fe^{3+}	0.176	0.092	0.066	0.064	0.047	0.030	0.084	0.116	0.035	0.060	0.084
Ca	2.003	1.946	0.294	0.276	2.167	1.960	2.167	2.263	0.050	0.107	0.159
Na	1.621	1.718	1.454	1.613	1.633	1.843	1.599	1.556	0.652	1.113	1.112
K	0.249	0.300	2.239	2.149	0.161	0.199	0.241	0.229	3.245	2.977	2.857
Ba	0.011	0.011	—	0.022	—	—	0.018	0.008	0.103	0.004	0.008
Σ	19.942	19.984	20.054	20.084	20.053	20.067	20.007	20.014	20.059	20.127	20.047
Or	6.6	7.8	57.4	54.5	4.1	5.1	6.2	5.8	83.0	72.0	70.3
% wt. Ab	40.5	41.9	35.1	38.5	39.5	44.6	38.5	37.1	15.7	25.4	25.8
An	52.9	50.3	7.5	7.0	36.4	50.3	55.3	57.1	1.3	2.6	3.9

[a] Based on 32 oxygens

[b] Below limit of detection (0.03% wt.)

Analyst: A.K. Ferguson

Table 2. Representative chemical analyses and structural formulae of feldspars from south-west Ugandan lavas of the leucitite series (C.2905) and basanites (C.2807)

% wt.	C.2905 (gm)					C.2807 (xl. in vug)		
	core——————→rim					core——————→rim		
SiO_2	62.1	63.2	64.0	63.9	63.2	55.5	56.5	57.8
Al_2O_3	20.0	19.2	18.5	17.8	18.5	26.9	25.5	24.5
Fe_2O_3	0.61	0.57	1.02	0.79	0.80	0.75	0.49	0.40
CaO	[c]	[c]	[c]	[c]	[c]	9.73	7.07	5.12
Na_2O	4.19	4.00	2.47	2.40	1.18	4.77	5.80	6.33
K_2O	9.70	10.6	12.5	13.4	15.2	0.89	1.43	3.25
BaO	3.10	1.78	0.96	1.21	0.56	0.65	1.44	1.55
Σ	99.70	99.35	99.78[b]	99.50	99.44	99.19	98.23	98.95
Cations[a]								
Si	11.573	11.736	11.850	11.921	11.822	10.132	10.430	10.650
Al	4.393	4.203	4.042	3.916	4.077	5.792	5.555	5.321
Fe^{3+}	0.086	0.080	0.142	0.111	0.113	0.103	0.068	0.055
Ca	—	—	—	—	—	1.902	1.397	1.011
Na	1.514	1.440	0.887	0.868	0.428	1.687	2.074	2.262
K	2.306	2.511	2.952	3.191	3.635	0.207	0.336	0.764
Ba	0.226	0.130	0.070	0.088	0.041	0.046	0.104	0.112
Σ	20.098	20.099	19.978[b]	20.096	20.115	19.869	19.965	20.175
Or	61.8	64.9	77.9	79.6	90.0	5.6	9.1	19.6
% wt. Ab	38.2	35.1	22.1	20.4	10.0	43.0	53.0	54.6
An	—	—	—	—	—	51.4	37.9	25.9

[a] Based on 32 oxygens

[b] Includes SrO = 0.33% wt., i.e. Sr = 0.035 cations

[c] Below limit of detection (0.03% wt.)

Analyst: A.K. Ferguson

Table 3. Representative chemical analyses and structural formulae of feldspars from the New South Wales BEH trachyte (70-1038), leucitite series, and East Eifel phonolite (E1)

% wt.	E1			70-1038	
	"phenoxl"			phenoxl	
	core	rim	gm	core	rim
SiO_2	65.1	64.6	63.0	63.0	65.0
Al_2O_3	18.8	18.4	18.8	20.6	17.7
Fe_2O_3	0.22	0.74	0.75	0.69	0.68
CaO	[b]	[b]	[b]	[b]	[b]
Na_2O	3.44	1.43	0.90	4.40	2.70
K_2O	12.7	15.2	15.4	9.20	12.2
BaO	[b]	0.35	0.54	2.60	1.40
Σ	100.26	100.72	99.39	100.49	99.48
Cations[a]					
Si	11.896	11.895	11.790	11.563	12.032
Al	4.049	3.994	4.147	4.457	3.862
Fe^{3+}	0.030	0.103	0.106	0.095	0.095
Ca	–	–	–	–	–
Na	1.219	0.511	0.327	1.566	0.969
K	2.961	3.571	3.667	2.154	2.834
Ba	–	0.025	0.040	0.187	0.102
Σ	20.155	20.098	20.086	20.022	19.892
Or	72.1	88.1	92.3	59.4	75.6
% wt. Ab	27.9	11.9	7.7	40.6	24.4
An	–	–	–	–	–

[a] Based on 32 oxygens

[b] Below limit of detection (0.03% wt.)

Analyst: A.K. Ferguson

by numerous occurrences besides those of the south-west Ugandan and Roman Regions, e.g. the Leucite Hills, Wyoming (Carmichael 1967; Barton and Hamilton 1979; Barton and van Bergen 1981); West Kimberley (Wade and Prider 1940) and New South Wales (Cundari 1973), Australia; Gaussberg, Antarctica (Sheraton and Cundari 1980).

The specimens investigated comprise typical material from the tephritic and leucitite series and south-west Ugandan basanites. Details of provenance, references and petrological data for representative specimens are given in the Appendix.

Analytical Technique

The chemical data were obtained from polished-thin sections of the selected specimens by means of an automated JXA-5A electron microprobe operated at 15 KV (accelerating voltage) and 0.02–0.03 μA (specimen current). Chemical standards were selected from natural and synthetic compounds. The results were corrected according to a method similar to that of Mason et al. (1969) and are considered accurate to within 2–5% for major and better than 9% for minor elements. Details of analytical procedures are in Ferguson and Sewell (1978).

Feldspar Chemistry

Representative feldspar analyses and structural formulae were selected to illustrate chemical variations with progressive crystallization in lavas of the tephritic series (Table 1), leucitite series (Tables 2, 3) and basanites (Table 3). The analyses were recalculated in terms of the feldspar components $KAlSi_3O_8$(Or)$-NaAlSi_3O_8$(Ab)$-CaAl_2Si_2O_8$(An), expressed as percent by weight. The sum of cations in the structural formulae ($W_4Z_{16}O_{32}$) fall within the range 19.9–20.1, i.e. ±0.5% of the theoretical 20.0. However, the low totals of most analyses suggest that undetermined Sr and/or Rb may be significant, e.g. up to ca. 0.8% wt. ($SrO+Rb_2O$). Rb contents estimated from relative peak heights are generally lower than Sr contents and less than ca. 0.2% wt. Rb_2O.

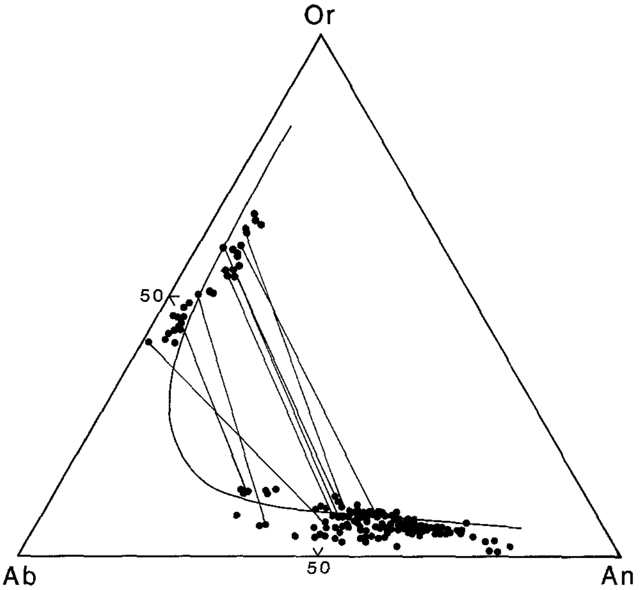

Fig. 1. Feldspar compositions from the south-west Ugandan (Bufumbira) tephritic series expressed in terms of $KAlSi_3O_8$(Or)$-NaAlSi_3O_8$(Ab)$-CaAl_2Si_2O_8$(An), weight per cent. The analytical values are in Ferguson (1978a; Table 5-1). Also shown is the solvus-solidus intersection at 900° C (Seck 1971). Tie-lines join the most Na-rich, coexisting feldspar compositions

Tephritic Series

Plagioclase and alkali feldspar commonly occur as coexisting "phenocrysts" in the lavas of this series. Alkali feldspar mantles both plagioclase and alkali feldspar and forms the groundmass of the phonolitic/trachytic lavas.

Plagioclase compositions from the south-west Ugandan lava suite become progressively enriched in K and Na (K- and Na-enrichment trends) and depleted in Ca (Ca-depletion trend) as crystallization proceeds (Fig. 1, Table 1). These trends are consistent with the Roman Region analogues (Baldridge et al. 1981; Cundari 1975, 1979). However, the plagioclase from the former suite is higher in K (mean [N=29] K=0.20±0.05 (σ) cations in the structural formula) by a factor of 2, relative to the latter (mean [N=13] K=0.08±0.06 (σ) cations in the structural formula) and distinctly exceeds the extent of Or_{ss} in plagioclase expected from the solvus-solidus intersection at 900° C in the system $KAlSi_3O_8-NaAlSi_3O_8-CaAl_2Si_2O_8-H_2O$ at $P_{H_2O}=$ 0.5 Kb (Seck 1971). Tie-lined feldspar compositions from the south-west Ugandan suite show that the most Na-rich alkali and plagioclase feldspars from individual lavas are generally consistent with Na-enrichment, K-, Ca-depletion

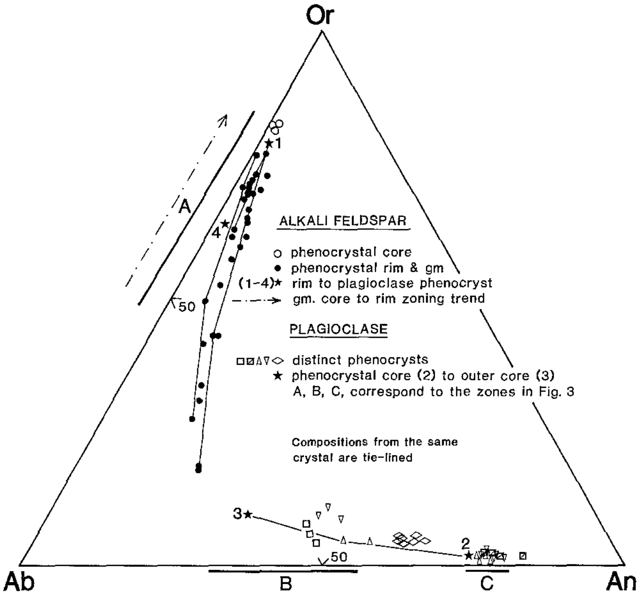

Fig. 2. Feldspar compositions from a leucite-phonolite of the Sabatini suite, Roman Region (Cundari 1979; SB.1), expressed in terms of $KAlSi_3O_8$(Or)$-NaAlSi_3O_8$(Ab)$-CaAl_2Si_2O_8$(An), weight percent. Numbered stars refer to point analyses across a zoned feldspar crystal (see Fig. 3). A, B, C approximately correspond to the zones in Fig. 3

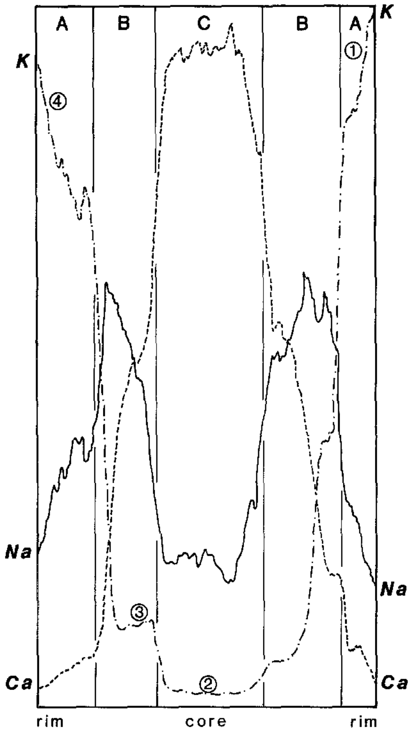

Fig. 3. Electron microprobe scan across a feldspar "phenocryst" from a leucite-phonolite of the Sabatini suite, Roman Region (Cundari 1979; SB.1). A, B, C are optically distinct zones, given also in Fig. 2. Encircled numbers 1 to 4 are point compositions (see Fig. 2) where the diameter of the circle is approximately that of the electron beam (ca. 10 µm). Vertical axis represents linear count rate

trends for the suite as a whole (Fig. 1). Some alkali and plagioclase feldspar compositions from the Roman Region are also consistent with these trends (e.g. Cundari 1975, Fig. 1; 1979, SB.1: Fig. 4), but others are not (e.g. Cundari 1979, SB.3: Fig. 4). Detailed chemical study of "two feldspars" assemblages confirms that analyses of core, rim and groundmass alkali feldspar may indeed show K-depletion, Na-, Ca-enrichment trends (e.g. SB.1, Table 1). However, alkali feldspar rims and groundmass in individual lavas are strongly zoned according to K-enrichment, Na-, Ca-depletion trends (e.g. SB.1, Fig. 2). Notably, alkali feldspar "phenocrystal" cores are slightly zoned (e.g. SB.1: Or_{85-80}). Likewise, coexisting plagioclase "phenocrysts" are relatively unzoned but their combined variation forms a wide compositional spectrum (e.g. SB.1: An_{83-53}, Fig. 2). Microphenocrystal and groundmass alkali feldspar may contain relatively unzoned plagioclase cores. A microprobe scan across one of these alkali feldspar-mantled plagioclases shows distinct growth zones (Fig. 3), their compositional variation being illustrated in Fig. 2. While Ca generally decreases and K increases from core to rims (zone C to A) with distinct gradient changes between zones, Na sharply inverts its increasing trend from C to B and generally decreases across the rims (zones A). The K-enrichment in the alkali feldspar rims ultimately approaches the values of the coexisting alkali feldspar "phenocrystal" cores (Fig. 2), similarly to the variation reported by Nash et al. (1969; Fig. 9) in the Mt. Suswa phonolites. Zones C and B may be attributed to pre-eruptive, possibly subvolcanic crystallization and only zones A are believed to represent crystallization at or near the volcanic T-P regime. Likewise, alkali feldspar-mantled alkali feldspar "phenocrysts" may represent genetically composite feldspars, only rim and groundmass compositions reflecting the volcanic crystallization regime. Variation trends based on "phenocrystal" core to rim compositions but neglecting rim and groundmass zoning trends may be misleading. For example, if rim and groundmass alkali feldspar compositions are lower in K relative to the cores (SB.1; Fig. 2, and Table 1) core to rim variation trends would be opposite to rim and groundmass zoning trends (cf. Carmichael et al. 1974; Baldridge et al. 1981).

Detailed investigation of "two feldspars" leucite-bearing lavas from Tristan da Cunha, south Atlantic, yielded no evidence to support alkali and plagioclase feldspar coprecipitation in the groundmass (Ferguson 1978a). Extensive K-enrichment (up to 30% wt. Or within single crystals) and Na-, Ca-depletion trends were reported by Ferguson (1978a) from this suite.

Leucitite Series and Basanites

In the lavas of the leucitite series, feldspar is generally found in accessory amounts in the groundmass and on vesicle walls. However, feldspar is the major constituent of trachytic pegmatoids genetically related to leucitites (e.g. 70-1038; see Appendix). Feldspar compositions from lavas of this series consistently show Na-depletion, K-enrichment trends, illustrated in Fig. 4. Ba contents are generally higher than those in the analogues from the tephritic series and depend on specific suites. Thus, alkali feldspar rim compositions from the New South Wales leucitites (e.g. 70-1038, Table 2) are distinctly higher in Ba than south-west Ugandan analogues (e.g. C.2905, Table 2) from host rock compositions with similar differentiation parameters (see Appendix). The suspected presence of significant Sr was

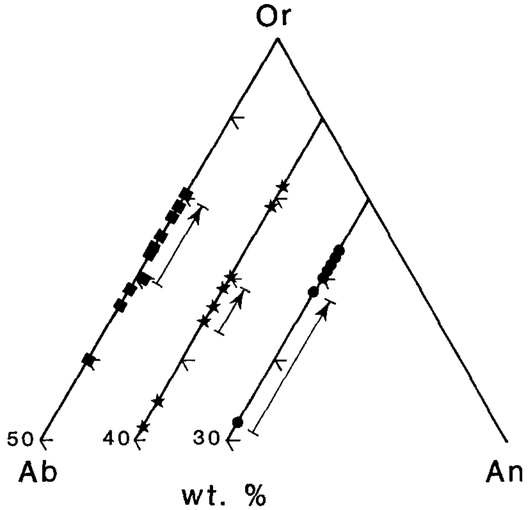

Fig. 4. Feldspars compositions from the New South Wales (BEH) leucitite suite (Cundari, 1973): *squares;* south-west Uganda leucitite suite (Ferguson 1978a): *stars;* Eifel phonolites (E1, E6; see Appendix): *circles.* Arrows indicate zoning trends in single crystals

confirmed in a feldspar composition from C.2905. However, accurate Rb analyses were not obtained.

Feldspars from the south-west Ugandan basanites typically occur as acicular crystals in the groundmass. These crystals represent some of the most Na-rich compositions of the south-west Ugandan suite and follow Ca-depletion and Na-, K-enrichment trends (e.g. C.2807, Table 2).

Discussion

Textural and compositional evidence suggests that "phenocrystal" feldspars were not in equilibrium with the host liquid during volcanic crystallization, as alkali feldspar generally mantles early-crystallized feldspars and forms the groundmass feldspar in the investigated lavas. Likewise, "phenocrystal" leucite is corroded to various degrees, particularly in phonolitic/trachytic lavas. Several distinct generations of feldspar "phenocrysts" may occur in a given host lava. However, "two feldspars" coprecipitation in the groundmass, i.e. under volcanic crystallization regime, cannot be substantiated in this study.

Alkali feldspar rim and groundmass zoning trends show K enrichment, Ca and Na depletion towards the outer zones. Alkali feldspar-mantled calcic plagioclase in the lavas of the tephritic series suggest a reaction relationship between plagioclase and the host liquid to generate alkali feldspar. Bowen (1956, p. 229ff.) considered this reaction relationship as "highly probable" in reference to "labradorite or anorthite surrounded by mantles of orthoclase", first reported by Washington (1906) in various lavas from the Roman Region and also "orthoclase occurring in zones surrounding labradorite" in shoshonite and banakite from Wyoming (Iddings 1895). If this reaction relationship applies to the above lavas, then fractionated high-K liquids similar to the Sabatini phonolites in composition may have followed a crystallization trend of progressive K enrichment in the Or_{ss} (cf. Bowen 1956, Fig. 59). However, the common occurrence of corroded leucite "phenocrysts" in the lavas of the tephritic series suggests that the host liquids have generally intersected the leucite stability field in the system $NaAlSiO_4-KAlSiO_4-SiO_2-H_2O$ (Fudali 1963) and subsequently reached the leucite-alkali feldspar peritectic boundary on the side of and close to the $NaAlSi_3O_8-KAlSiO_3O_8$ join (e.g. Cundari 1979, Fig. 4). The K-enrichment, Ca-, Na-depletion trends of the alkali feldspar compositions require that possible host liquids on the leucite-alkali feldspar boundary should follow a concave rather than a convex path toward the ternary invariant point R in the join $NaAlSiO_4-KAlSiO_4-SiO_2$ (cf. Fudali 1963, Fig. 10). Fractionated liquids within the leucite stability field trending toward the $NaAlSi_3O_8-KAlSi_3O_8$ join would leave the leucite-alkali feldspar boundary with incompletely reacted leucite crystals and terminate their crystallization course in the alkali $feldspar_{ss}$ stability field. These liquids, represented by phonolitic/trachytic groundmass residua, may crystallize alkali $feldspar_{ss}$ progressively enriched in K following concave/inflected crystallization paths

Appendix

Specimen	Rock type[a]	Locality	Reference	mgNo.[b]	A.I.[c]	D.I.[d]
Tephritic series:		*S.W. Uganda:*				
C.2799	phonolitic tephrite	Muhavura	Holmes and Harwood (1937: p. 177ff.)	50.2	0.67	57.6
C.2871	latite	Bitare	Holmes and Harwood (1937: p. 182)	47.9	0.67	59.3
		Roman Region, Italy:				
SB.1	phonolite	Sabatini	Cundari (1979)	87.3	0.76	78.0
		East Eifel, Germany:				
E1, E6	phonolites	Rieden	Duda and Schmincke (1978)	57.1	0.65	–
Leucitite series:		*S.W. Uganda:*				
C.2905	leucitite	Kitale	Holmes and Harwood (1937: p. 96)	64.8	0.86	42.3
		New South Wales, Australia:				
70-1038	trachyte	Begargo Hill	Cundari (1973)	63.1	0.90	39.6
Basanites:		*S.W. Uganda:*				
C.2807	basanite	Lutale	Holmes and Harwood (1937: p. 74)	71.2	0.69	29.8

[a] Classification and nomenclature according to Streckeisen (1967)
[b] mgNo. = 100 $Mg/Mg+Fe^{2+}$ (mol)
[c] A.I. = $Na+K/Al$ (mol)
[d] D.I. = Differentiation Index (Thornton and Tuttle 1960)

mgNos., A.I. and D.I. for the SW Ugandan lavas were calculated from Ferguson's (1978a) new analyses.

toward the "ternary" minimum (cf. Nash et al. 1969). The sporadic occurrence of nepheline in the lavas of the tephritic series suggests that the residual liquids were generally exhausted before reaching the nepheline-alkali feldspar cotectic boundary leading to the above minimum.

The presence of modal pyroxene in natural phonolitic/trachytic liquids may significantly influence the crystallization path of these liquids and their precursors, projected in the "residua system" $NaAlSiO_4-KAlSiO_4-SiO_2-H_2O$ (Edgar 1974). It should be noted that addition of $NaFe^{3+}Si_2O_6$ and Na_2SiO_3 to the system $NaAlSi_3O_8-KAlSi_3O_8-SiO_2-H_2O$, i.e. the silica oversaturated section of the above system, at $P_{H_2O}=1{,}000$ Kg/cm^2, progressively moves the minimum on the quartz-feldspar cotectic boundary toward more K-rich compositions (Carmichael and Mackenzie 1963). However, the effects of plagioclase and clinopyroxene crystallization cannot be evaluated in the "residua system" (cf. Norris and MacKenzie 1976). The field of primary plagioclase appears to be considerable reduced in the system $CaMgSi_2O_6-NaAlSiO_4-NaAlSi_3O_8-H_2O$ at $P_{H_2O}=1$ Kb (Edgar 1964). Also, the pyroxene phase volumes increase markedly, relative to the plagioclase volume, with increments of $CaMgSi_2O_6$ over $NaFeSi_2O_6$ in the system $NaAlSi_3O_8-NaAlSiO_4-NaFeSi_2O_6-CaMgSi_2O_6-H_2O$ at $P_{H_2O}=1{,}000$ Kg/cm^2 (Nolan 1966). The sporadic occurrence of plagioclase in clinopyroxenite ejecta and inclusions associated with leucite-bearing lavas (e.g. Holmes and Harwood 1937; Fornaseri et al. 1963; Cundari 1982) confirms that plagioclase crystallization was largely subordinate to that of pyroxene in the subvolcanic pressure regime. On the other hand, experimental crystallization of representative lavas from the Vico and Sabatini suites at atmospheric pressure and fO_2 close to the Ni/NiO buffer, CO_2 and air, respectively, indicates in all cases that leucite is the liquidus phase and the onset of pyroxene crystallization generally occurs at lower temperatures, relative to that of the plagioclase (Cundari, unpublished data). Pyroxene crystallization is, therefore, expected to influence the phase equilibria in residual liquids at least to the same extent as that of the plagioclase. The chemistry of the pyroxene from leucite-bearing lavas and their differentiates is distinct in the tephritic and leucitite series, respectively, and is closely related to the (Na+K)/Al ratio of the host rock (Cundari and Ferguson 1982). Generally, the pyroxene from lavas of the tephritic series is lower in Ca, relative to the leucitite series analogue. Pyroxene crystallized in low-temperature residua of the leucitite series under volcanic pressure regime typically attained late-stage Na enrichment, reflecting a strongly alkaline to peralkaline nature of these liquids. Thus in the Begargo Hill (BEH) differentiated leucitite suite from New South Wales the extreme groundmass pyroxene composition is titanian aegirine (essentially $Na_{0.91}Fe^{3+}{}_{0.55}-Ti_{0.25}Si_{1.9}O_6$; Cundari and Ferguson 1982; Table 4) and the coexisting alkali feldspar followed a K-enrichment trend to potash sanidine (70-1038, Table 3). Crystallization of euhedral groundmass nepheline (Ne: Ks = 82–89 : 18 – 11) preceded that of interstitial alkali feldspar ($Or_{55}Ab_{45}-Or_{80}Ab_{20}$) and both phases followed K-enrichment, Na-depletion trends (Cundari 1973; Figs. 6, 7). Notably, the compositional variation of feldspathoids reported by Carmichael et al. (1974, p. 246) and Baldridge et al. (1981) in lavas from the Roman Region followed core to rim and phenocrysts to groundmass K-enrichment trends. Leucite compositions from lavas of the tephritic series are commonly non-stoichiometric and their variation in the Na/K ratio are largely subordinate to the (Si+Al)>(K+Na) leucite variation trend (Cundari 1975).

Finally, F and Cl and/or alkali fluorides and chlorides are expected to influence feldspar crystallization in leucite-bearing lavas, particularly in residual groundmass assemblages. F and Cl values of ca. 0.1% wt., respectively, are common in the southwest Ugandan suite (Holmes and Harwood 1937). Late-crystallized mica from lavas of this suite contain up to ca. 5% wt. F and ca. 0.1% wt. Cl; micas from the Vico suite, Roman Region, up to 5.6% wt. F and 0.1% wt. Cl; late-crystallized mica from the New South Wales suite 1.9 to 3.1% wt. F (Ferguson 1978a). Notably, the alkali feldspar minimum in the system $NaAlSi_3O_8-KAlSi_3O_8-H_2O$ is shifted toward K-rich compositions in the presence of an alkali chloride vapour (cf. Roux and Varet 1975).

Concluding Remarks

The textural relationships of coexisting plagioclase and alkali feldspar consistently evince a sequential feldspar crystallization, the latter following the former, rather than a cotectic one. Similar to the associated pyroxene (Cundari 1975, 1979), individual "phenocrystal" feldspars from the same lava specimen may show a wide spectrum of core compositions. Also, the compositional variations of "phenocrystal" feldspars from the same lava suite may not follow coherent crystallization trends. Crystallization trends based on "phenocrystal" core to rim compositional variations may not indicate the feldspar course of crystallization in the host lava, as the core compositions may be related to different liquids prior to eruption. A direct genetic relationship between "phenocrystal", i.e. presumed xenocrystal, feldspars and the host lava is, therefore, suspect and only groundmass feldspars, i.e. feldspars crystallized under the volcanic T-P regime, are considered as reliable indicators of crystal-liquid relationships in the host lavas.

The groundmass alkali feldspar from all investigated lavas consistently indicate Ca-, Na-depletion and K-enrichment zoning trends. These trends are opposite to the Roman Region analogue trends reported by Baldridge et al. (1981; Fig. 3) and cannot be accounted for by the hypothetical line of liquid descent proposed by Carmichael et al. (1974; Fig. 5–14) in the system $NaAlSiO_4-KAlSiO_4-CaAl_2Si_2O_8-SiO_2$ ("The phonolite pentahedron"), as yet incompletely known experimentally. Also, this system does not account for the pyroxene crystallization, expected to be important particularly in the lavas of the leucitite series, nor for the Sr and/or Ba feldspar components, notable in the groundmass feldspar compositions of some Sabatini lavas (Cundari 1979; Table 3).

Theoretical phase relationships bearing on the liquid evolution of leucite-bearing lavas are as yet unsupported by adequate information, but should be consistent with the following:

1. Plagioclase and alkali feldspar crystallization under the volcanic T-P regime is *sequential,* rather than cotectic, at least in the Roman Region and south-west Ugandan suites investigated.
2. Groundmass alkali feldspar consistently follows K-enrichment, Na-, Ca-depletion trends.

3. Plagioclase crystallization generally follows Ca-depletion, Na-, K-enrichment trends.

4. The limit of Or_{ss} in plagioclase from the southwest Ugandan suite exceeds the solvus-solidus intersection at 900° C in the system $KAlSi_3O_8-NaAlSi_3O_8-CaAl_2Si_2O_8-H_2O$ at $P_{H_2O}=0.5$ Kb (Seck 1971).

Also, the following emerge as factors capable of influencing feldspar crystallization trends in the investigated lavas:

1. Significant Sr and Ba solid solubility, particularly in groundmass feldspars.

2. Crystallization of coexisting pyroxene with distinct chemistry in the tephritic and leucitite series, respectively.

3. Presence of F, Cl and/or their alkali compounds during feldspar crystallization.

While these factors remain unevaluated and the experimental data for the relevant systems are incomplete, generalizations on feldspar crystallization trends in leucite-bearing and related rocks must be considered as speculative.

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