The problem of the potash-rich basaltic rocks

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Summary. It is suggested that the name shoshonite be revived for a group of potash-rich basalts and that the magma from which monzonites, potash-rich syenites, many lamprophyres, nepheline monzonites, shonkinites, covites, ijolites, leucite basalts, leucitophyres, etc., have crystallized be called the shoshonite magma-type. This series shows parallels with the alkali basalt magma series, and the question of the relation of the two magma-types is discussed.

The name latite is discussed and rejected as a name for this potash-rich magma type. It is further shown that rocks of this composition invade geosynclinal regions that have been recently stabilized, one group of shoshonites being associated with an environment that is still subjected to minor folding and showing some relation to the calc-alkaline rocks, the other a true alkaline suite associated with non-orogenic conditions.

IN New South Wales there are several occurrences of basaltic rocks containing potassium feldspar in addition to plagioclase, and they seem to belong to a distinct magma-type. This magma differentiates towards potash-rich trachytic rocks and these types also occur at Port Cygnet in Tasmania. Although these rocks show some affinities to the alkali basalts there is no place for them in the alkali basalt–hawaiite–mugearite–trachyte differentiation series. Some types chemically resemble the trachybasalts and trachyandesites of the alkali basalt suite, but differ from them mineralogically in containing labradorite and potassium feldspar instead of oligoclase and potassium feldspar or a potassium-rich oligoclase. Furthermore, unlike the trachybasalts and trachyandesites, the potash-rich basalts are not individual members of a differentiation series, but themselves form a differentiation series which includes pyroxenite, olivine monzonite, banatite, syenite porphyry, and lamprophyres as well as the undersaturated types nepheline monzonite, shonkinite, covite, ijolite, jacupirangite, sanidine tinguaite, and sanidine–hauyne–melanite porphyry.

Extrusive types have been called latites (Harper, 1919) and have been compared with lavas in the Sierra Nevada, which Ransome (1898) considered the effusive equivalents of the Tyrol monzonites. Some of the intrusive rocks have been compared to types in Montana, Arkansas, and the Fen District of Norway (Brown, 1930; Edwards, 1947). In Montana some of the shonkinites are associated with leucite basalts.

In the Woods Point–Walhalla district of Victoria Hills, and in the Snowy Mountains of N.S.W. (Joplin, 1964) there are dyke-swarms and co-linear stocks consisting of pyroxenite, monzonite, orthoclase-bearing diorite, and numerous types of lamprophyre, and though some of these rocks differ from the above-mentioned members of the potash-basalt suite, most of them are closely allied and I believe that they have crystallized from the same magma under slightly different tectonic conditions.

This paper is concerned with the nomenclature of some of the potash-rich basalts, with their tectonic environment and with their relation to the alkali basalt magma.

Nomenclature. Some of the basaltic rocks near Gerringong, N.S.W., are called latites, so an inquiry must be made into the original meaning of this term, which Ransome applied as a *group name* to lavas formerly called basalts in the Sierra Nevada. He pointed out that these lavas contained very high alkalis, particularly potash, and inspection of his analyses shows that Na_2O/K_2O ranges from 1/1 to 1/2. Ransome called these rocks latites because he considered that they resembled trachydolerites described by Washington (1897) from the Latium Province of Italy; he believed them to be the effusive equivalents of the monzonites. Further, he suggested that the quartz banakites of the absarokite–shoshonite–banakite series of Yellowstone Park (Iddings, 1895) may be the felsic dyke equivalents of the latites. As Iddings regarded the banakites as feldspathic modifications of the shoshonite magma and complementary to the feldspar-poor absarokites, it is surprising that Ransome compared his latites only with the banakites and did not consider them as possible members of Iddings's series (see table I). In attempting to name the lavas near Gerringong on the south coast of N.S.W., Card (Harper, 1919) finally called them latites, but he first called them basalts, basaltic andesites, orthoclase basalts, and trachytes (Card and Jaquet, 1903; Jaquet, Card, and Harper, 1905) and remarked (1905), with reference to the name shoshonite, 'if the latter name were generally recognized in geological literature its use here would be thoroughly justified'.

A comparison of tables I and II will show that these rocks are characterized by high alumina, lime, and potash.

The name latite now has a very wide meaning, but Ransome's latites were porphyritic rocks containing phenocrysts of labradorite and augite

TABLE I. Shoshonite Series of Yellowstone Park and Sierra Nevada

	I	II	III	IV	V	VI	VII	VIII	IX	X
SiO_2	50·06	51·75	52·86	53·49	54·97	56·19	56·78	57·29	60·89	62·33
Al_2O_3	17·00	17·48	17·51	17·19	18·38	16·76	16·86	18·45	17·14	17·35
Fe_2O_3	2·96	6·42	5·18	4·73	3·06	3·05	3·56	4·38	3·32	2·98
FeO	5·42	1·46	3·31	3·25	4·22	4·18	2·93	1·20	0·95	1·63
MgO	3·61	4·05	4·18	4·42	2·38	3·79	3·41	2·08	1·16	1·05
CaO	8·14	8·20	6·51	6·34	5·43	6·53	6·57	3·57	3·58	3·23
Na_2O	3·53	3·33	3·22	3·23	3·45	2·53	3·19	4·43	4·54	4·21
K_2O	3·40	3·72	3·41	3·86	3·37	4·46	3·48	5·43	5·71	4·46
H_2O^+ H_2O^-	4·85	2·26	1·76	2·17	0·82	0·66 0·34	1·21 0·15	2·18	1·61	0·75 0·44
CO_2	—	—	—	—	2·92	—	0·18	—	—	—
TiO_2	0·51	0·86		0·71	0·97	0·69	1·15	0·72	0·49	1·05
P_2O_5	0·66	0·67	0·53	0·43	0·42	0·55	0·42	0·46	0·27	0·29
MnO	0·14	tr	tr	0·14	tr	0·10	—	tr	0·09	0·08
BaO	—	—	—	0·06	—	0·19	—	—	—	0·24
NiO	—	—	—	—	—	—	—	0·12	0·19	—
Li_2O	—	—	0·04	—	0·03	—	—	—	—	—
SrO	—	—	—	—	—	—	—	—	—	0·44
Cl	—	tr	0·16	—	—	—	—	—	—	—
SO_3	—	0·17	0·22	—	0·03	—	—	—	—	—
FeS_2	—	—	—	—	—	—	—	—	—	0·08
C	—	—	—	—	—	—	—	—	—	0·11
			99·93							
Less O = F			0·03							
Total	100·28	100·37	99·90	100·02	100·45	100·02	99·89	100·31	99·94	100·33

I. Shoshonite, Bison Peak, Yellowstone Park, Anal. L. G. Eakins.
II. Shoshonite, Sepulchre Mountain, Yellowstone Park. Anal. J. E. Whitfield.
III. Shoshonite, Beaverdam Creek, Yellowstone Park, Anal. J. E. Whitfield.
IV. Shoshonite, Beaverdam Creek, Yellowstone Park. Anal. L. G. Eakins.
V. Shoshonite, Bear Gulch, Montana. Anal. J. E. Whitfield.
VI. Augite Latite, Table Mountain, Sierra Nevada.
VII. Augite Latite, Table Mountain, Sierra Nevada.
VIII. Quartz Banakite, Stinkingwater River, Yellowstone Park, Anal. W. H. Melville.
IX. Quartz Banakite, Stinkingwater River, Yellowstone Park, Anal. W. H. Melville.
X. Biotite–augite–latite, Clover Meadow, Sierra Nevada.

TABLE II. Shoshonite Series of eastern Australia

	I	II	III	IV	V	VI	VII	VIII	IX	X
SiO_2	51·09	51·11	51·32	52·12	53·90	54·05	55·68	58·82	61·25	64·49
Al_2O_3	16·11	17·70	18·82	18·47	15·32	16·14	16·08	14·78	18·59	17·48
Fe_2O_3	3·11	3·99	4·50	3·40	3·60	4·25	3·55	3·90	1·58	1·64
FeO	6·58	5·13	2·97	4·77	5·13	3·67	3·85	3·24	2·18	1·69
MgO	4·69	3·43	3·58	5·11	2·41	3·23	2·92	2·26	0·58	0·66
CaO	9·10	6·51	6·42	8·71	7·30	6·39	6·18	3·09	4·05	3·28
Na_2O	3·29	3·97	3·97	3·07	3·73	3·60	3·55	4·67	4·30	4·16
K_2O	3·94	3·25	3·31	3·29	3·44	3·72	3·72	4·70	4·06	4·79
H_2O^+	0·66	2·41	2·89	0·46	0·97	1·08	0·69	1·36	0·42	0·52
H_2O^-	0·10	0·52	0·87	—	0·74	1·46	1·63	0·81	0·60	0·18
CO_2	abs	0·01	0·10	—	0·03	0·16	0·28	0·05	abs	0·71
TiO_2	1·02	1·34	0·56	tr	2·86	1·09	0·91	1·78	1·28	0·46
P_2O_5	0·77	0·65	0·42	0·25	0·55	0·98	0·71	0·58	0·61	0·22
MnO	0·18	0·32	0·23	tr	0·36	0·19	0·21	0·23	0·42	0·11
BaO	—	0·07	0·22	—	0·06	0·08	0·12	0·12	—	—
NiO	—	0·02	0·01	—	0·02	0·02	0·01	0·02	—	tr
CuO	—	—	0·02	—	0·01	—	—	—	—	—
V_2O_3	—	0·05	0·04	—	0·02	tr	—	0·02	—	—
Cl	—	0·01	tr	—	0·02	—	—	—	—	—
F	—	—	—	—	—	0·09	0·13	—	—	—
S	—	—	—	—	—	—	—	—	—	0·06
						100·20	100·22			
Less O = F						0·04	0·05			
Total	100·64	100·49	100·25	99·65	100·47	100·16	100·17	100·43	99·92	100·45

I. Monzonite, Mt. Dromedary, N.S.W. Anal. I. A. Brown.
II. Porphyritic Monzonite, Milton, N.S.W. Anal. H. P. White.
III. Minamurra Latite, South Coast, N.S.W.
IV. Hornblende Lamprophyre, Tilba Tilba Lake, N.S.W. Anal. J. C. H. Mingaye.
V. Monzonite Porphyry, Milton, N.S.W. Anal. H. P. White.
VI. Bumbo Latite, South Coast, N.S.W. Anal. J. H. Pyle.
VII. Bumbo Latite, South Coast, N.S.W. Anal. J. H. Pyle.
VIII. Cambewarra Latite, South Coast, N.S.W. Anal. H. P. White.
IX. Syenite Porphyry, Port Cygnet, Tasmania. Anal. A. B. Edwards.
X. Banatite, Mt. Dromedary, N.S.W. Anal. I. A. Brown.

and/or olivine and biotite in a groundmass of labradorite, augite, and potash-rich glass. These rocks compare closely with absarokites and shoshonites except that labradorite is mantled with orthoclase in the rocks from Yellowstone Park and they do not necessarily contain glass. Some of the American absarokites and shoshonites also contain leucite. Iddings (1913) remarked on the resemblance between the Table Mountain latite and the shoshonites, and suggested that it was transitional between the shoshonites and other Sierra Nevada latites, and he also compared these rocks with one from the south coast of N.S.W.

These rocks together with their plutonic equivalent, the monzonites, are clearly alkaline basaltic rocks, but the names latite and monzonite are now applied also to calc-alkaline types. The reason for this change in the meaning of latite may possibly be found in the wider meaning given to monzonite since Brøgger introduced the name quartz monzonite for a rock with a monzonitic fabric containing quartz and orthoclase. Gradually quartz monzonite has come to mean an adamellite with about 67 % of silica and containing orthoclase, oligoclase-andesine, quartz, green hornblende, and biotite. The quartz monzonites are commonly associated with granodiorites and granites and their effusive equivalents are the dellenites, which Johannsen (1931) regarded as synonymous with quartz latites.

The original monzonite of the Tyrol, however, contained labradorite, orthoclase, clinopyroxene, and biotite, and some varieties olivine, and in the field these rocks are associated with pyroxenites, potash syenites, and syenite aplites (Ogilvie Gordon, 1903). This assemblage in the Tyrol compares with that at Mt. Dromedary on the south coast of N.S.W. (Brown, 1930) and with some of the Montana occurrences (Larsen, 1940), though at Mt. Dromedary and in Montana extremely undersaturated rocks are associated, the more basaltic types commonly containing nepheline and/or leucite and a calcium-rich pyroxene, and the more trachytic types nepheline, leucite, hauyne, nosean, melanite garnet, and a sodic pyroxene or amphibole. I would venture to say that melanite, and possibly hauyne and nosean, occur only in trachytes associated with the shoshonites, and are not present in rocks associated with the alkali basalt magma.

As Ransome intended latite to be used as a group name for rocks intermediate between andesites[1] and trachytes the wider meaning which includes the calc-alkaline rocks is perhaps justified. With the wider meaning in mind, Nockolds (1954) placed latites and monzonites

[1] At this time the term andesite included hawaiite.

together in his division 'no essential quartz or feldspathoid with potassium feldspar between 40 per cent and 60 per cent of the total feldspar', thus implying that the names latite and monzonite may be applied to both alkaline and calc-alkaline rocks. Nevertheless, in referring to East Central Sierra Nevada, Nockolds and Allen (1953) have stated 'two series are present—a normal calcalkaline series ranging from pyroxene andesite to rhyolite, and a somewhat later latite series', but they have listed a quartz-latite-porphyry as a typical member of a calc-alkaline suite. In their 1954 paper, graphs are drawn for the Sierra Nevada latite series which is listed with the alkaline rocks, though they indicate its calc-alkaline affinities.

It is customary to name a magma series after its effusive mafic member, but owing to the confusion over the name latite, there is good reason for not applying it to the group of alkaline basaltic rocks characterized by high potash, and for using instead the name shoshonite, which, moreover, has three years priority over latite. I therefore propose that the name shoshonite be applied to this magma series.

Trachydolerites (now commonly referred to as trachybasalts) and trachyandesites are associated with alkali basalts in stable regions and with andesitic rocks in orogenic regions, and all these rocks qualify as latites when that term is used in its wider meaning. I suggest that the names trachybasalt and trachyandesite be retained for individual members of these suites, and if the term latite is used at all it be used in the broad sense of Nockolds's classification.

Tectonic environment. Ransome stated that the latite flows of Sierra Nevada are intercalated with pyroclastic rocks covering a surface carved out of vertical schists and plutonic rocks and that tilting, which gave rise to the present slope of the peneplain, began at the time of vulcanicity. Obviously, this is a non-orogenic environment, vulcanism having occurred during the late stages of stabilization.

Thom (1955) considers that volcanic eruptions at Yellowstone Park took place in the Oligocene and early Miocene when valleys cut in the Laramide fold mountains were infilled with ash. Here again is the picture of an area in a late process of stabilization and no longer subjected to folding.

Ogilvie Gordon (1903) considered that the monzonitic complex of Monzoni was emplaced in stages along fault zones, and later subjected to slight folding, so again a late process of stabilization is indicated though possibly a little earlier than the American examples.

The so-called latites on the south coast of N.S.W. are interbedded with fossiliferous Permian tuffs which were laid down in an exogeosyncline (Voisey, 1959) later uplifted but not folded, and the complexes at Mt. Dromedary and Port Cygnet were intruded during the Cretaceous (Evernden and Richards, 1962) when the Tasman geosyncline was almost stable.

In the Woods Point–Walhalla area of Victoria and near Kiandra in the Snowy Mountains of N.S.W. pyroxenite, monzonite, orthoclase gabbro, orthoclase diorite, and many lamprophyres occur as dyke-swarms or co-linear stocks. These dioritic rocks typically contain high potash, whereas diorites occurring as satellites on the margins of bathyliths normally contain higher soda than potash. The Victorian dykes are cut by granitic ring-dykes and subjected to minor folding, and though this environment is less stable than those described above, it still indicates a late phase of the geosyncline. Although most of these rocks compare closely with the shoshonites some differ in containing green hornblende and orthopyroxene. As both minerals are common in the calc-alkaline rocks of the orogenic regions, it is assumed that they have developed in these shoshonitic rocks when water pressure was still high and some features of the true orogenic environment were still present.

The trachybasalts and trachyandesites of the alkali basalt suite are found in non-orogenic areas, and those associated with the andesitic suite occur in the orogenic regions. Calc-alkaline quartz monzonites also occur in the orogenic environment.

Relation to the alkali basalt magma. Rocks of latitic composition are plotted in fig. 1 and a rough separation into tectonic environments is apparent. Plots of members of the alkali basalt suite made by Muir and Tilley (1961) are reproduced and the curve extrapolated to include the mugearite–trachyte, and it will be seen that the curve for the Australian Tertiary alkali basalt suite is of similar shape. Actually there is some scatter of points on both curves and it is probable that the whole suite falls in a band rather than on single curves.

Most of the shoshonitic rocks fall in a band to the right of the alkali basalts, and most of the Yellowstone Park shoshonites are on the right-hand side of this band.[1] The banatite from Mt. Dromedary and two of the Gerringong rocks fall to the left of the band. These are late-stage differentiates with a trachytic composition, so it is assumed that they have moved in this direction as a result of high fractionation (Bowen, 1928). The band of the shoshonites roughly follows the course indicated

[1] TiO_2 may be low and Al_2O_3 consequently slightly high in these old analyses.

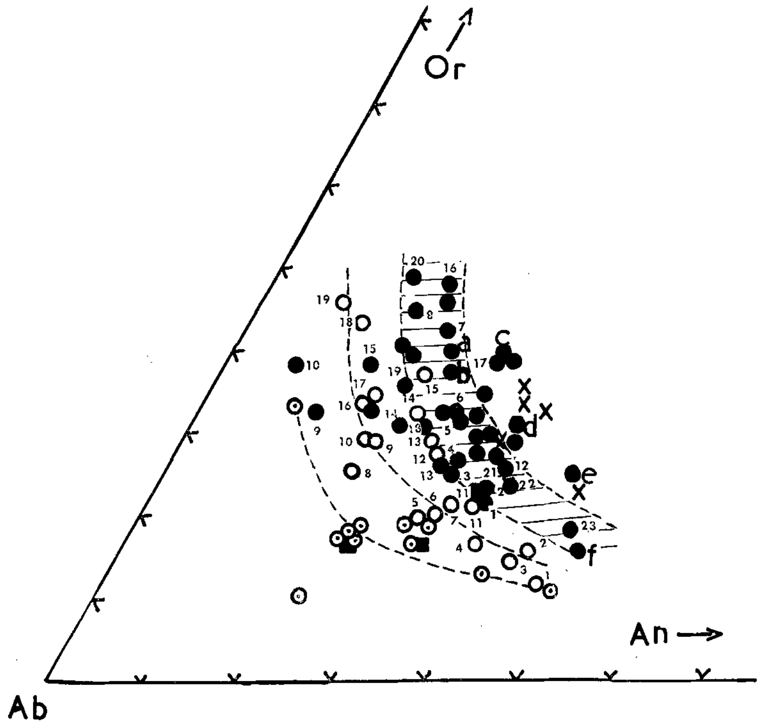

FIG. 1. Triangular plot of basaltic rocks based on normative albite-anorthite-orthoclase

Solid square and points enclosed in circles (un-numbered) show differentiation trend of alkali basalt magma (Muir and Tilley, 1961, fig. 6). Open circles (numbered 1–19), differentiation of alkali basalt magma, eastern Australia: 1–3 = Alkali Basalts, Victoria; 4–6 = Hawaiites (Victoria, Queensland, N.S.W.); 7–8 = Mugearites (Victoria and Queensland); 9–10 = Hypersthene Trachyandesites (Victoria); 11–13 = Trachybasalts (Victoria); 14–15 = Trachyandesites (Victoria); 16–17 = Trachybasalts (Victoria); 18–19 = Trachyandesite (N.S.W.). Solid circles (numbered 1–23), Australian shoshonites: 1–10 = Gerringong Volcanics, N.S.W.; 11–14 = Milton, N.S.W.; 15–17 = Mt. Dromedary, N.S.W.; 18–20 = Port Cygnet, Tasmania; 21–23 = Kiandra, N.S.W. Solid circles (un-numbered), shoshonites, Yellowstone Park, and latites, Sierra Nevada. Solid circles (lettered *a-f*), Monzonites, Tyrol. Crosses = monzonites and trachyandesites of orogenic regions Georgetown Inlier, Queensland, New England and Hartley, N.S.W.

by Bowen for the formation of a liquid rich in potash when there is low fractionation.

Monzonites and trachyandesites of the orogenic regions plot to the right of the shoshonite band, and there is evidence to show that most of these are hybrids.[1] It may be significant that alkali basalts and shoshonites falling to the right of their normal curves can also be shown to be hybrids or contaminated rocks. As most of the shoshonitic rocks of the dyke-swarms have been metasomatized, only those from Kiandra are plotted.

The trend of the shoshonite band indicates that these rocks form a differentiation series not unlike that of the alkali basalt series, and the fact that deviation of the trends takes place from about the same point suggests that the shoshonite has been derived from the alkali basalt magma and that separation took place at an early stage. There is some suggestion that deviation may have been caused by an initial contamination of the deep-seated magma, but it may have been caused by a special type of differentiation or by differential melting of the mantle material.

For convenience of presentation in a textbook on the petrography of the Australian Igneous Rocks (Joplin, 1964) I have subdivided the alkali basalts into two groups—the near-undersaturated and the undersaturated rocks. The first is undersaturated only with respect to olivine and includes the alkali basalts, hawaiites, mugearites, anorthoclase basalts, trachybasalts and trachyandesites, trachytes, comendites, and pantellerites and the second group is undersaturated with respect to both olivine and feldspathoids and includes the teschenites, basanites, analcitites, theralites, nepheline basalts, nephelinites, monchiquites, and melitite basalts.

It is possible to divide the shoshonites in a similar manner, the near-undersaturated shoshonites including pyroxenites, monzonites, orthoclase gabbros, orthoclase diorites, banatites, sanidine porphyries, and most types of lamprophyre, whilst the completely undersaturated group contains nepheline monzonites, shonkinites, covites, ijolites, leucite basalts, leucitophyres, sanidine tinguaites, and sanidine–hauyne–melanite porphyries. Leucite monchiquites are also associated with this magma, but analcite and nepheline monchiquites occur with members of the undersaturated alkali basalts. Camptonites occur with both the alkali basalts and shoshonites, but other lamprophyres such as spessartites, vogesites, kersanites, minettes appear to be associated only with the shoshonites, particularly with those that are emplaced at an early stage in the stabilization of the geosyncline.

Like the rocks of the alkali basalt suite, the shoshonites are charac-

[1] Work in progress on the New England Bathylith, N.S.W., by B. W. Chappell, Department of Geology, Australian National University.

terized by calcium-rich pyroxenes,[1] and a brown alkali amphibole is recorded in some of the rocks from the Woods Point Walhalla dyke-swarm.

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[1] Analyses of a number of pyroxenes from different members of the complex at Mt. Dromedary will shortly be published by R. S. Boesen, Department of Geophysics, Australian National University.