SHOSHONITES AND ASSOCIATED ROCKS OF CENTRAL BRITISH COLUMBIA

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INTRODUCTION

The belt of Upper Triassic volcanic sequences of central British Columbia has long been recognized to contain a mixture of alkaline potassic, alkaline sodic, as well as calc-alkaline suites. A similar association is also found in the Lower Jurassic sequences that occur within this belt and in the Eocene sequences of the Ootsa Lake-White Lake belt.

This paper demonstrates, and in some cases confirms, the shoshonitic nature of the alkaline potassic suites of Upper Triassic, Lower Jurassic, and Eocene age. Interest in the recognition of such volcanism was prompted at first by the identification, from chemical data, of shoshonitic lenses (Basic Schist Unit of Thorstad, 1983) intruding, or interlayered with, the arc tholeiitic Kutcho Creek Formation and by the subsequent preliminary examination of data from Upper Triassic and Lower Jurassic sequences as part of a general review of the chemical composition of volcanic sequences in British Columbia.

A brief bibliographic review of the shoshonitic association in the world, followed by the chemical pattern of these shoshonites obtained from certain petrologic diagrams, serve as an introduction to the review of shoshonitic associations of central British Columbia. The latter include suites from the Upper Triassic Stuhini, Takla, and Nicola Groups; the Lower Jurassic Toodoggone, Horsefly, and Rossland sequences; and a few sequences from the Eocene Kamloops and Penticton Groups. Emphasis is placed on shoshonites for petrological, tectonic, and economic reasons: (1) shoshonites, once considered a petrological oddity, have gained full petrological status - at least amongst island arcs petrologists - since so many shoshonitic suites have been recognized in arcs of the southwest Pacific, Italy, Puerto Rico, and Kamtchatka; (2) they reflect collision periods and disturbance of subduction zones and therefore may shed light on the collision history of allochthonous terranes of central British Columbia; (3) associated copper and gold deposits occur commonly as epigenetic vein systems in the shoshonitic volcanic piles and as porphyry copper-gold in comagmatic alkaline intrusions.

THE SHOSHONITIC ASSOCIATION

Shoshonite, together with shonkinite, absarokite, and banakite, were described and named by Iddings (1895) in the Eocene units of Yellowstone Park. About the same time, Washington (1897, 1906) described the ciminite-vulsinite-toscanite series and associated leucitic rocks of western Italy, and Ransome (1898) the latite series of Sierra, Nevada. All these series are equivalent and belong to the shoshonite association. Johannsen (1938), however, thought that these terms represented petrological oddities and should be discarded; Streckeisen (1967) ignored them. In 'Alkaline Rocks' (Sorensen, 1974) only shonkinite is briefly mentioned and nothing is said about alkaline rocks of island arcs.

The chemical and tectonic importance of shoshonites as the product of a specific alkaline potassic magma were recognized by Joplin (1964, 1965, 1968) while comparing rocks from Australia; Yellowstone Park; Sierra, Nevada; Italy; and Indonesia. She pointed out the characteristic value of the ratio $K_2O/Na_2O \geqslant 1$, the low Ti content and the high Al content occurring with Ca and Mg abundances similar to subalkaline rocks (in spite of the very high potash content). She proposed the terms 'shoshonite association' to encompass an alkaline potassic series from basalt to rhyolite, trachyte, and phonolite, depending on the degree of silica saturation, and divided it into two groups (1) 'near-saturated' including shoshonites *sensu stricto*, alkaline rhyolite, and trachyte, and (2) 'undersaturated' including the rarer leucitic rocks. Joplin also pointed out that this particular type of volcanism occurred at a time of stabilization, at the close of a period of active tectonism. Nicholls and Carmichael (1969), on the other hand, thought that it was unnecessary to elevate the shoshonitic association to a special status.

Subsequently, numerous studies documented the existence of shoshonites in Fiji (Dickinson, 1968; Gill, 1970), New Hebrides (Gill and Gorton, 1971), Papua-New Guinea (Jakes and White, 1969; Johnson, 1971; Mackenzie and Chappell, 1972; Smith, 1972), Solomon Islands (Hackman, 1971), Italy (Appelton, 1972; Ninkovich and Hays, 1972; Barbieri, *et al.*, 1974), and Puerto Rico (Jolly, 1971).

These studies substantiate the validity of Joplin's chemical distinction and its tectonic significance. All authors, Ninkovich and Hays excepted, attribute the generation of shoshonites to collision of plates resulting in the disturbance of the subduction zone, its 'jamming' and, in some cases, its reversal.

To the shoshonitic association of volcanic rocks and associated comagmatic intrusive rocks defined by Joplin, one must add the alkaline ultramafic intrusions of Alaskan type. In Alaska, Irvine (1973) demonstrated that the alkaline picritic potassic basalts of Bridget Cove could be the source (by crystal settling) of the nearby alkaline ultramafic intrusions of Early Cretaceous age. Similarly, he linked the Upper Triassic alkaline ultramafic intrusions of British Columbia to the surrounding more differentiated volcanic rocks of the Takla Group (Irvine, 1976). It seems, however, that these volcanic rocks, and hence the related Alaskan-type ultramafic intrusions, were recognized as belonging to the newly established shoshonitic association only by Delong (1975) for the Briget Cove basalts and by Meade (1977) for the Takla volcanics.

High-K calc-alkaline volcanism commonly precedes or is associated with shoshonites (Eolian Islands, Papua-New Guinea, New Hebrides, Fiji). A complete gradation from high-K andesites to shoshonites and a similar trace-element signature throughout the series were documented by Mackenzie and Chappell (1972). In areas devoid of recognized shoshonites, the presence of high-K andesites may imply similar tectonic conditions.

NOMENCLATURE AND CHEMICAL PROFILE

The petrographic nomenclature is complex and confusing as it reflects the original definitions given to similar rock types by several authors (*see* Joplin, 1968). As a result, some authors even reject specific names in favour of the more general terms. The nomenclature given in Table 1 is that of Mackenzie and Chappell (1972) for the shoshonites of the Highlands of New Guinea, to which trachyte and liparite have been added. This nomenclature applies only for the 'near-saturated' group. For the rarer 'undersaturated' group, Appleton's classification for the leucitic rocks of the Roman Province is used.

TABLE 1
NOMENCLATURE OF THE NEAR-SATURATED ASSOCIATION

SiO_2 Range	Name	Includes	General Name
<50%	Absarokite	Ciminite	Trachybasalt
50-57%	Shoshonite	Banakite	Trachybasalt
		Latite	Low-Si Trachyandesite
		Vulsinite	
57-63%	Latite	Q banakite	High-Si trachyandesite
	$K_2 < 6\%$	Vulsinite	Trachyte
	High-K trachyte		
	$K_2 < 6\%$		
>63%	Toscanite	Q latite	Alkaline dacite
	Liparite		Alkaline rhyolite

Shoshonites were described by Joplin as having $K_2O/Na_2O \geqslant 1$, together with high Al, Ca, and Mg and low Ti. Mackenzie and Chappell (1972) proposed $K_2O/Na_2O \geqslant 0.6$ *for 50 per cent* SiO_2 *and* $\geqslant 1$ *for 56 per cent* SiO_2. This classification holds for most shoshonites except for those of Bufumbira (Uganda) which have a high Ti content. More importantly, there are other alkaline potassic rocks with similar K_2O/Na_2O ratios, which do have leucitic members, and with which shoshonites may be and have been confused. These fall into two unrelated groups: potasso-sodic (including the kamafugites) and orenditic.

The variation diagrams used were MgO, CaO, Na_2O, K_2O, Alk, FeO_T, and Al_2O_3, as well as TiO_2 versus FeO_T. Specific compositional domains have been defined on all except Al_2O_3:SiO_2 as illustrated for the Upper Triassic suites on Figures 135 to 143 (pages 438 to 442).

All three potassic series were found to plot in the alkaline domain of Alk versus SiO_2 (Kuno's boundary), and in the very high-K (VHK) and extreme high-K (EHK) domains of K_2O versus SiO_2; most are in the subalkaline domain on MgO versus SiO_2. All three series also show regular decrease in Fe content and a steep increase from 10 to 12 per cent Al_2O_3 in picritic basalts and up to 22 per cent for some trachytes and phonolites of the shoshonitic and potasso-sodic series. An Al_2O_3 decrease appears only for latites and rhyolites. Orenditic suites have typically lower Al_2O_3 contents, increasing from 7 to 12 per cent.

Titanium was found to be characteristic of the tectonic setting just as in subalkaline basalts. On TiO_2 versus FeO_T, shoshonitic and potasso-sodic basalts of island arcs and continental margins plot in the low-Fe part of the island arc and ridge domains (these domains were defined for subalkaline basalts), whereas the continental and oceanic potasso-sodic suite, as well as the continental Bufumbira shoshonites, plot in the within-plate domain. Orenditic suites are all in the within-plate domain.

Shoshonitic and potasso-sodic series are best separated by their Na content. Shoshonitic series fall within the subalkaline domain on Na_2O:SiO_2, whereas the potasso-sodic series are above it. In addition, Ca content of shoshonitic series tend to be higher: CaO values are mainly in the subalkaline domain, though those of the more undersaturated suites are below it, whereas all potasso-sodic suites plot below, or at best straddle, the lower subalkaline boundary.

Orenditic series differ from the shoshonites by their lower Al_2O_3 contents; in the critial 10 to 12 per cent Al_2O_3 range, orendites are markedly more potassic.

SHOSHONITES OF BRITISH COLUMBIA

The suites examined include: (1) the Upper Triassic Stuhini Group in the Galore Creek area (Panteleyev, personal communication, 1984; Allen, *et al.*, 1976) and further east, near the Hotailuh batholith (Anderson, 1983), the Takla Group near the Hogem batholith (Meade, 1977), the Nicola Group south of Kamloops (Preto, 1979), and the Basic Schist unit of the Kutcho Creek Foramtion (Thorstad, 1983); (2) the Lower Jurassic Toodoggone volcanics (Schroeter, 1982; Forster, 1984), Horsefly Group (Morton, 1976), and Rossland Group (Daly, 1912; Little, 1960); (3) the Eocene Kamloops Group (Ewing, 1981; Church and Evans, 1983) and the Penticton Group (Church, 1973).

The shoshonitic character of the alkaline potassic suites was recognized by Meade (1977) for the Takla Group (units 7b, 7c, 8) and by Church for the Penticton Group (high-K trachyandesite and trachyte of the 'B' series). At Galore Creek, in the Stuhini Group, Allen *et al.* (197±6) compared the unusual leucitic phonolites and syenites to the Mediterranean and western Alaskan assemblages. Other authors, such as Lefebure (1976) and Preto (1979) for the Nicola Group and Morton (1976) for cycle I of the Horsefly Group, compared them to the potassic volcanics of Gough and Tristan da Cunha Islands which are, however, more sodic and Ti rich, befitting their oceanic setting. Anderson (1983) and Ewing (1981) classified the basalts of the Stuhini and Kamloops Groups as calc-alkaline because of their saturated composition, in spite of their high alkali content. Both authors implicitly define as alkaline, only rocks deficient in silica and therefore eliminate many saturated and oversaturated rocks, and hence many shoshonites, from the alkaline family.

UPPER TRIASSIC

Shoshonites

To simplify and reduce the great number of petrogenetic diagrams, only data from the shoshonitic sequences within the Stuhini, Takla, and Nicola (central belt) Groups were plotted (Figs. 135 to 143) to illustrate their chemical characteristics. The associated subalkaline and alkaline, more sodic, volcanic analyses were omitted deliberately.

The occurrences of the most common alterations, which involve Ca and/or Mg (and therefore Na) were assessed on MgO/CaO diagrams, on which all suites, from calcic to the most alkaline (cumulates excepted), plot in a domain labelled 'unaltered' (de Rosen-Spence, 1976). This domain is narrow enough to make it useful for screening data. Of 71 samples, 40 plot in the 'unaltered' domain, thus providing a sound base for interpreting other diagrams. Twenty-three analyses plot as altered and eight have gained Ca or have plagioclase cumulates. The Nicola shoshonites are by far the most altered with only two 'unaltered' samples among the available analyses.

The MgO content of most samples plot in the 'subalkaline' domain of MgO/SiO_2 (Fig. 136), none above it. There is thus no evidence of extensive Mg metasomatism.

Figures 137 to 139 show that the Upper Triassic potassic volcanics of central British Columbia are unequivocally shoshonites. The CaO content (Fig. 137) of the unaltered samples is equivalent to that of subalkaline rocks. Only the most undersaturated trachybasalts and phonolites of Galore Creek are deficient in CaO. Most altered samples, however, show an expected overall decrease in CaO relative to the unaltered samples.

The Na_2O contents (Fig. 138) of unaltered samples are also similar to those of subalkaline rocks, whereas the K_2O contents (Fig. 139) are much higher, and plot predominantly in the very high-K (VHK) and extreme high-K (EHK) domains. Most of the extreme values belong to the highly undersaturated Upper unit of Galore Creek (Stuhini Group). The few abnormally high and low Na values can be ascribed to replacement of Ca and/or K by Na, and Na by K respectively as the same samples display corresponding low Ca and/or K and extreme high-K values.

The alkaline character, evident on Alk versus SiO_2 (Fig. 140) where Kuno's boundaries are traced, is due mainly to the high K_2O contents. The Irvine-Baragar's boundary would cut across the lower cluster of points giving a false impression of mixed character to British Columbia shoshonitic rocks.

The regular decrease in FeO_T (Fig. 141) and dramatic increase in Al_2O_3 (Fig. 142) are typical of alkaline potassic suites. The plot of TiO_2 values for basalts with $48 \leqslant SiO_2 \leqslant 50.5$, in the island arc domain of TiO_2 versus FeO_T (Fig. 143) confirm the tectonic setting of these shoshonites, which could be surmised from their close association with high-Al and calc-alkaline *sensu stricto* sequences.

All suites, except the Galore Creek Upper unit (Stuhini), belong to the 'near-saturated' group as defined by Joplin. All suites are composed mainly of shoshonites *sensu stricto* accompanied by some absarokites. Latites occur also in the Galore Creek Lower unit (Stuhini) and toscanites have been identified in the Triassic-Jurassic volcanic sequence which overlies the Stuhini Group near the Hotailuh batholith.

The Galore Creek Upper unit is composed mainly of rocks of the 'undersaturated' group, and pseudoleucite has been identified in several flows. The analyses compare well with the least undersaturated rocks of the Roman Province and comprise phonolitic tephrites, tephritic phonolites, and leucite phonolites. A few near-saturated shoshonites are also present.

Associated Rocks

Subalkaline rocks associated with the shoshonites belong to medium-K and high-K calc-alkaline (*sensu stricto*) and high-Al basaltic suites. Their stratigraphic position is uncertain in many cases, and they could interfinger with the shoshonites as in the Toodoggone volcanics and Penticton Group. The following were identified:

(1) medium-K and high-K andesites in the Galore Creek Lower unit;

(2) high-K and high-Al basalts showing Fe enrichment in the Stuhini Group, Hotailuh area;

(3) in the Takla Group, high-K basaltic andesites (unit 4c), probably a time equivalent with the shoshonites (units 7b, 7c, 8); medium-K basalts and basaltic andesites with high-Al (unit 6b) and tholeiitic (unit 7a) affinities below the shoshonites; medium-K calc-alkaline andesite (unit 9c) above the shoshonites, and separated from them by a more sodic alkaline unit (9a); and

(4) in the Nicola Group (central belt), medium-K, high-Al, Fe-enriched, basalts at the alkaline limit are probably the lateral extension of similar andesites and rhyolites of the western belt which are thought to be younger than the shoshonites (Preto, 1979). This high-Al sequence is similar to that of the Newberry volcano which sits behind the Cascades chain.

Alkaline sodic rocks may have medium to very high-K contents and may be nepheline or quartz normative. The tend to follow (with one exception) the shoshonites and separate them from medium-K calc-alkaline volcanism. The following were identified:

(1) in cycle I of Triassic-Jurassic volcanics overlying the Stuhini Group (Hotailuh area): high to very high-K, Ne-normative trachyandesites, associated with shoshonitic toscanites and followed by cycle II comprising medium-K basaltic andesites and dacites;

(2) in the Takla Group: medium to high-K trachybasalts and trachyandesites (units 2, 4a) underlie or are equivalent to the shoshonites; mildly alkaline, quartz-normative andesites (unit 9a) are intermediate between latites and mildly sodic trachyandesites and overlie the shoshonites; and

(3) in the Nicola Group: medium to high-K, Q-normative trachyandesites are associated with shoshonites of the eastern belt; similar comagmatic microdiorites intrude the shoshonites of the central belt.

All associated rocks, whether subalkaline or alkaline, have titanium contents typical of island arcs, with the exception of the high-Al sequence of the Nicola Group which plots in the ridge domain.

LOWER JURASSIC

Shoshonitic sequences, similar to those of Upper Triassic age have been identified amongst the Lower Jurassic sequences which overlie the alkaline Upper Triassic belt previously described. Calc-alkaline and alkaline sodic sequences are also present.

The Toodoggone volcanics are an assemblage of high-K calc-alkaline and shoshonitic lavas and tuffs. In the area sampled by Schroeter (1982) high-K andesites occur with latite flows and are overlain by altered trachyte tuffs. In the area studied by Forster (1984), the sequence is composed of high to near medium-K andesites and dacites with only minor interbedded shoshonitic trachyte. These successions suggest the coexistence of two different volcanic centres erupting concomitantly alkaline and calc-alkaline magmas.

In the Horsefly Group, where Morton (1976) recognized three successive cycles, only cycle I contains absarokites and shoshonites. Cycles II and III are more sodic: cycle II is high-K sodic, and cycle III is very high-K potasso sodic with $K_2O = Na_2O$.

In the Rossland Group (Daly, 1912; Little, 1960) the sequence is composed of shoshonites and latites and had been classified as latitic (Ransome's definition) by Daly.

EOCENE

In the Kamloops Group, the Salmon Arm basalts and andesites (Church and Evans, 1983) and the basalts analysed by Ewing (1981) are potassic and mildly alkaline. They plot as shoshonites leading to an oversaturated trend. Those analysed by Ewing are associated with calc-alkaline andesites and rhyolites.

In the time-equivalent Penticton Group, Church (1973) recognized shoshonitic trachytes (group 'B') interbedded with calc-alkaline andesites and rhyolites (group 'A'), underlain by more sodic alkaline porphyry and phonolite. A few of Church's andesites are shoshonites, less alkaline than the trachytes. In more detail, the Kitley Lake trachyte, Kearns Creek shoshonites, and Nimpit Lake trachytes form a first group, and the White Lake shoshonites and Skaha trachytes a second group, separated by calc-alkaline andesites (Park Rill) and rhyolite (Marama).

TECTONIC AND OTHER IMPLICATIONS

The recognition of the alkaline potassic volcanism in British Columbia as shoshonitic is important for its tectonic significance; shoshonitic volcanism is linked with collision of plates, disturbance, even reversal, and finally dying of a subduction zone. It is therefore most interesting to observe that the Upper Triassic and Lower Jurassic shoshonites occurred during the period of 'docking' of the Stikinia, Cache Creek, Quesnellia, and Eastern terranes and their accretion to North America. The occurrence in a narrow belt of contemporaneous medium-K, high-K, and very high-K volcanism requires a steeply dipping subduction zone during Upper Triassic and Lower Jurassic times. The coexistence during the Lower Jurassic of the narrow Toodoggone-Rossland arc and the wide Hazelton arc to the west, would require a distinct subduction zone for the Hazelton arc.

If the Philippines arcs (Divis, 1980) are taken as a model, one could envisage that the Upper Triassic subduction zone, after being disturbed by the collision of the allochthonous terranes and having generated the calc-alkaline-shoshonitic Nicola-Takla-Stuhini arc as it became subvertical, was eventually reversed during accretion to North America before dying, generating hence the Toodoggone-Rossland arc. At that time a new subduction zone was already operating further west generating the Hazelton arc. This model is intended, of course, to be very general and does not take into account relative north-south motions of the different blocks, nor the possibility that the Upper Triassic arc was actually double, separated by the Cache Creek terrane.

The Eocene shoshonites probably are linked to the disturbance of the subduction zone at their time of formation. Collision of other allochthonous terranes also may have played a role.

The Upper Jurassic-Lower Cretaceous shoshonites of western Alaska also occurred after 'docking' of the Wrangellia and Alexander terranes.

From a practical point of view the abundance of shoshonite and alkali-rich rocks is encouraging to the explorationist. The alkaline character of numerous porphyry-type deposits has been known for many years in the Canadian Cordillera but the possible association of epithermal gold systems with alkali-rich sequences is a much more recent concept.

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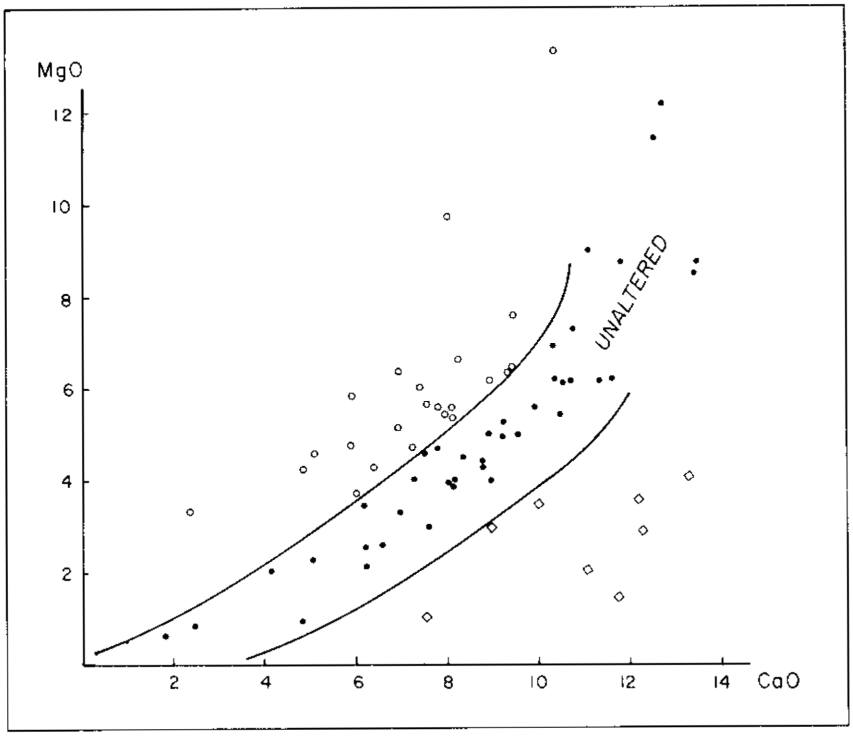

Figure 135. Upper Triassic shoshonites. MgO:CaO plot designed to screen 'unaltered' (filled circles), 'altered' (open circles) samples, and samples with 'added Ca' or plagioclase cumulates (squares). Unaltered domain from de Rosen-Spence (1976).

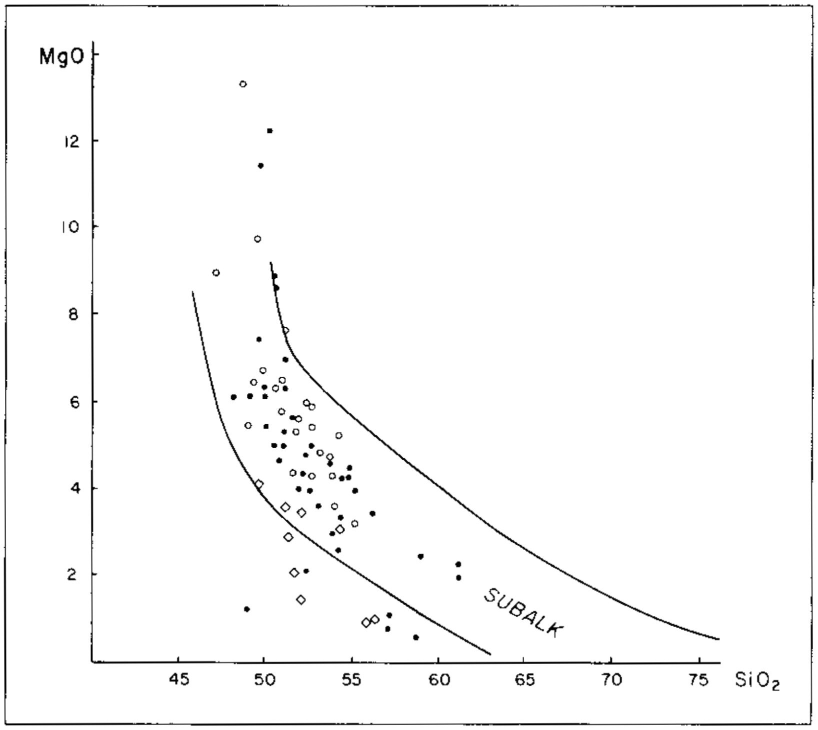

Figure 136. Upper Triassic shoshonites. MgO:SiO_2 plot, notice absence of data points above the 'subalkaline' domain. Boundaries from de Rosen-Spence (1976).

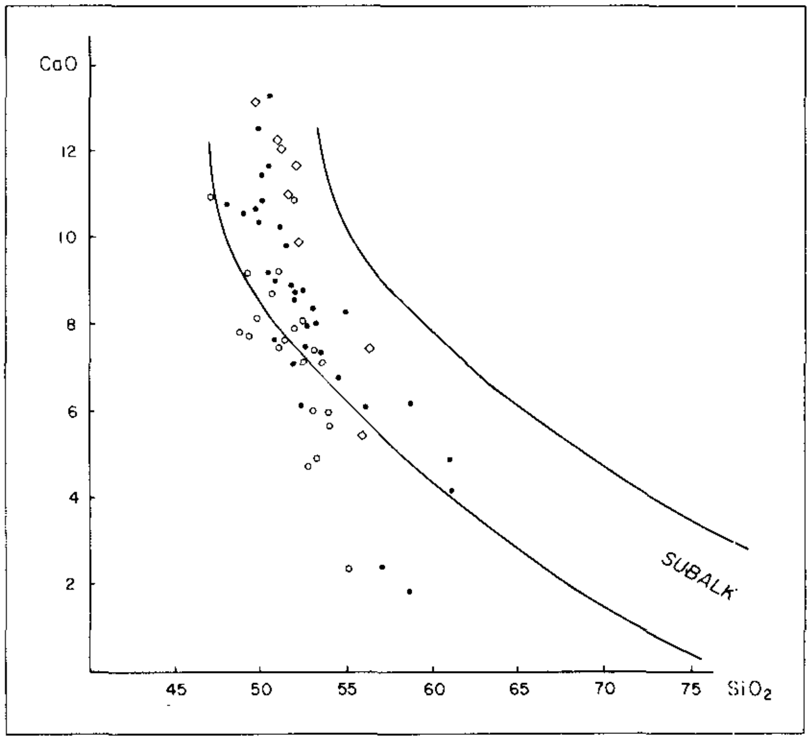

Figure 137. Upper Triassic shoshonites. CaO:SiO_2 plot shows majority of 'unaltered' data points in 'subalkaline' domain. Boundaries from de Rosen-Spence (1976).

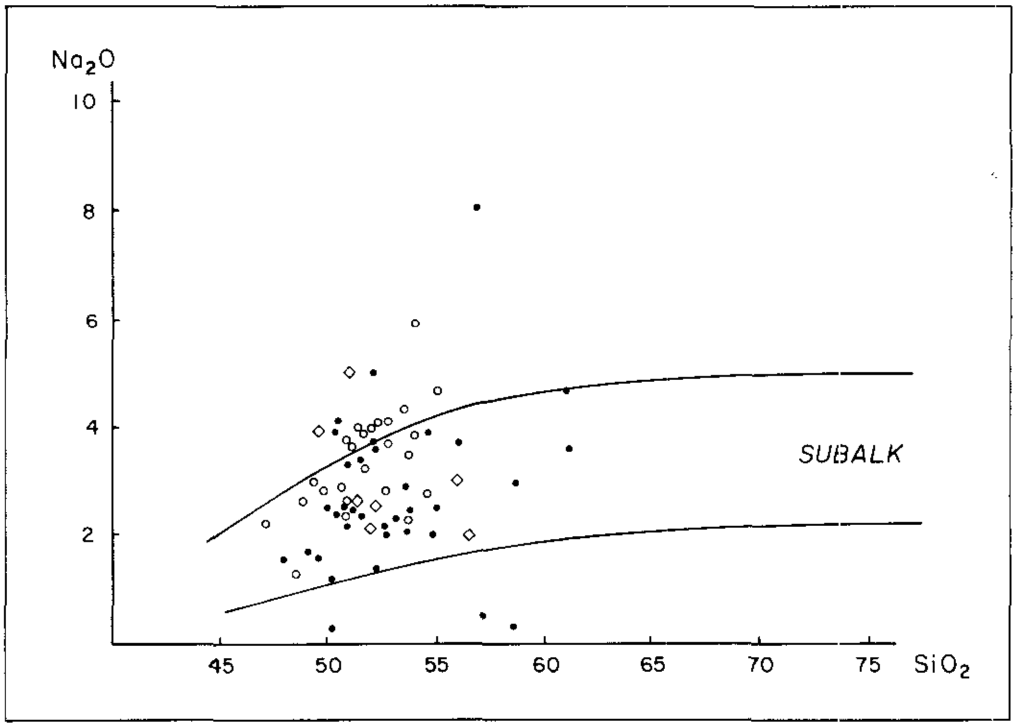

Figure 138. Upper Triassic shoshonites. Na_2O:SiO_2 plot shows most data points in 'subalkaline' domain. Those above it have lower K_2O contents. Boundaries from de Rosen-Spence (1976).

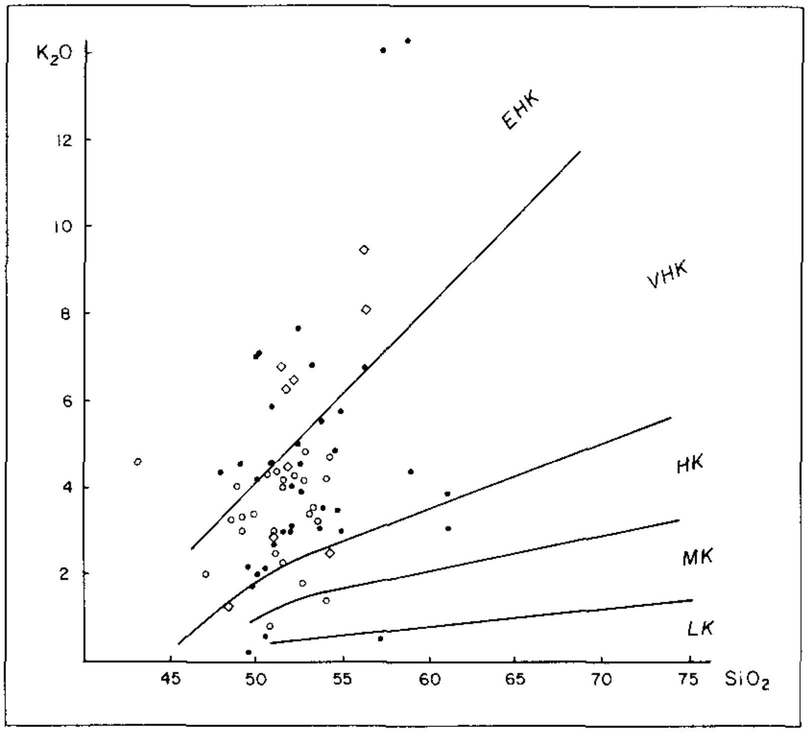

Figure 139. Upper Triassic shoshonites. K_2O:SiO_2 plot illustrates the highly potassic nature of the shoshonites. Points below the 'very high-K' domain correspond to samples with above normal Na_2O on Figure 138. Low (LK), medium (MK), and high (HK) K_2O domains from Gill (1981); very high (VHK) and extreme high (EHK) K_2O domains from this study.

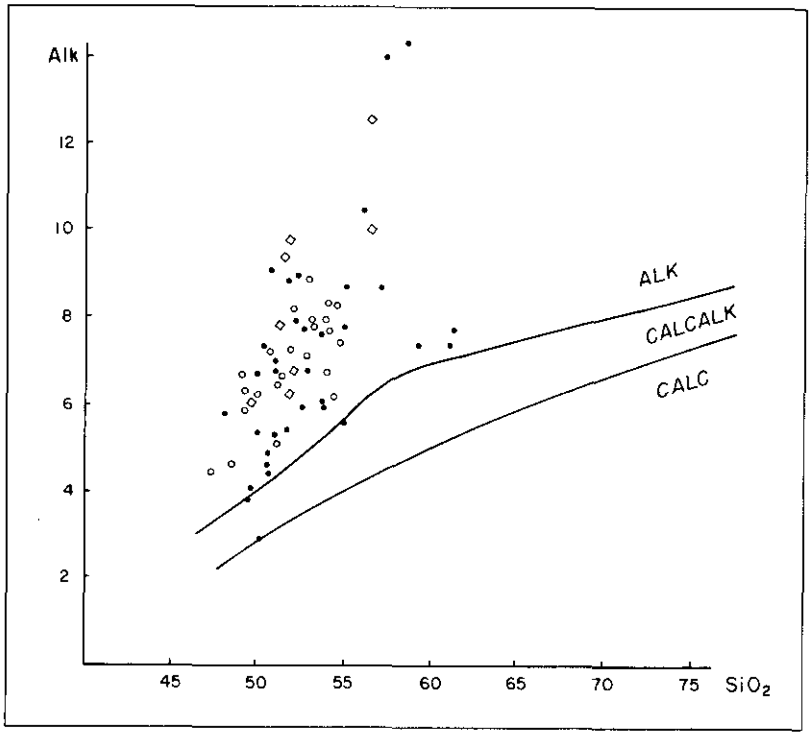

Figure 140. Upper Triassic shoshonites. Alk:SiO_2 plot illustrates the alkaline nature of the shoshonites. *The extremely alkaline samples are leucite phonolites.* Boundaries from Kuno (1966), high-Al domain relabelled 'calc-alkaline' and thoelitic domain 'calcic'.

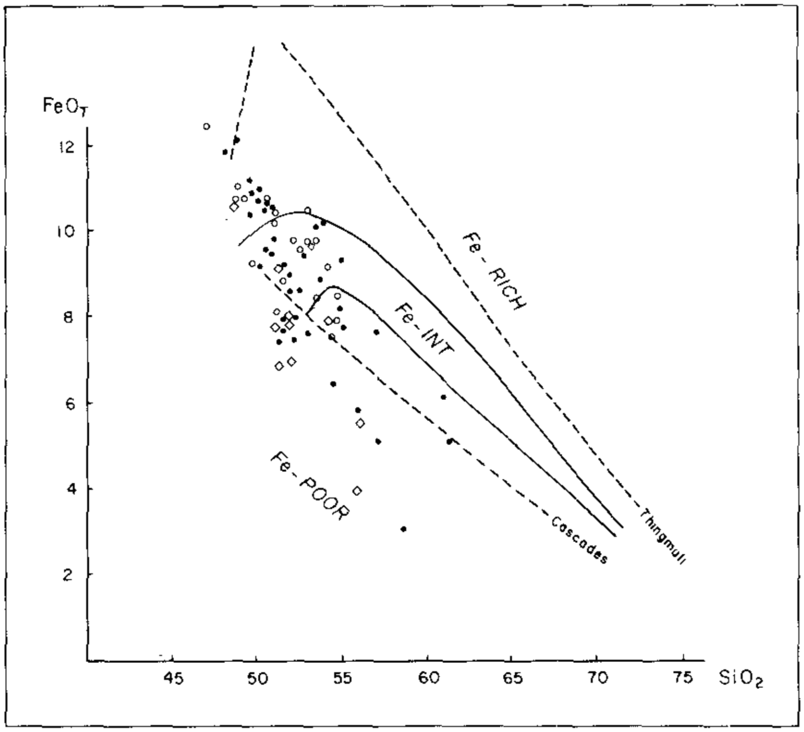

Figure 141. Upper Triassic shoshonites. FeO$_T$:SiO$_2$ plot. 'Fe-rich' (tholeiitic) and 'Fe-poor' (calc-alkaline) domains defined from plot of pigeonitic and hypersthenic suites of Japan. 'Fe-intermediate' domain is a zone of overlap (de Rosen-Spence, 1976).

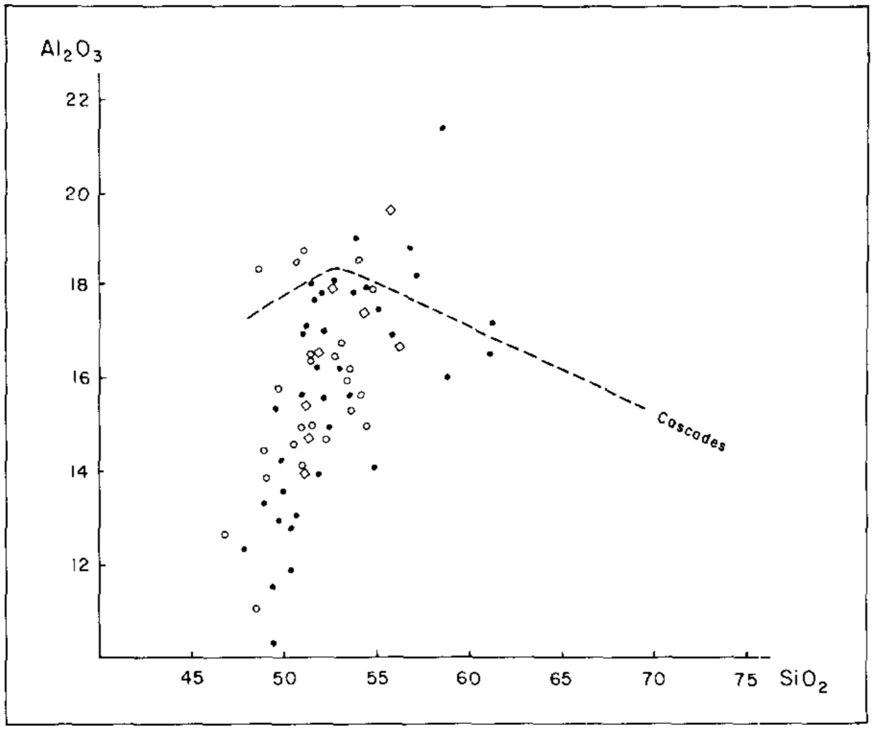

Figure 142. Upper Triassic shoshonites. Al$_2$O$_3$:SiO$_2$ plot shows the increase in Al$_2$O$_3$ with differentiation.

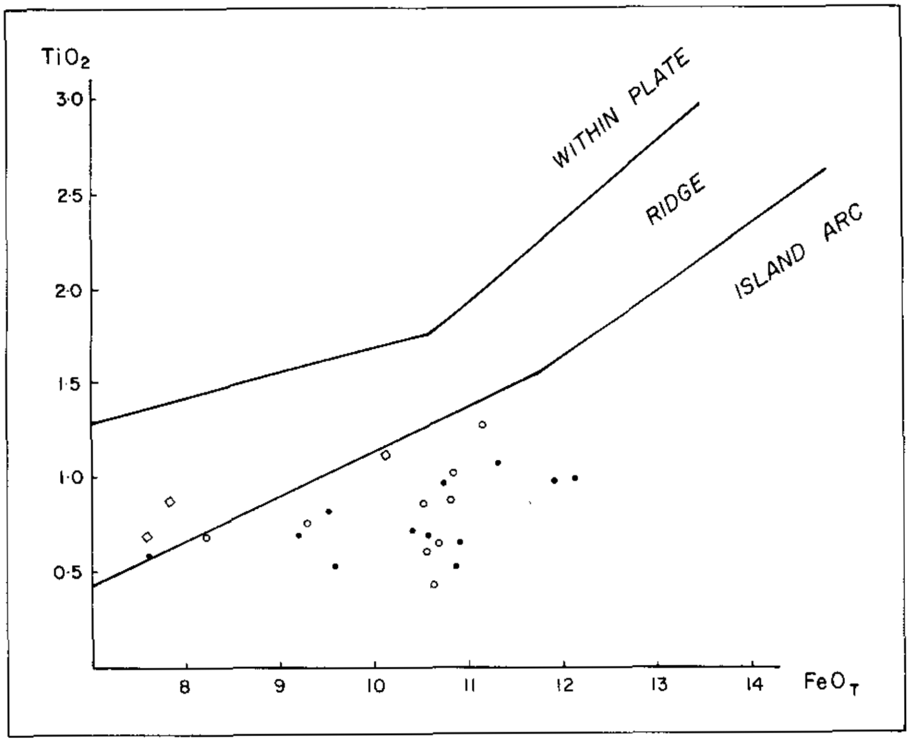

Figure 143. Upper Triassic shoshonites. TiO_2:FeO_T designed initially for subalkaline basalts with 48 per cent ≤ SiO_2 ≤ 50.5 per cent (de Rosen-Spence, 1976).