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## **Petrology and Chemistry of Precambrian Alkaline Rhyolites from Western Bahia (Brazil)**

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With 4 Figures

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### **Summary**

The petrology and chemistry of alkaline rhyolites from Western Bahia State are investigated. Original mineralogy and bulk chemistry are modified by secondary processes (cataclastic metamorphism, hydrothermal leaching). The overall chemistry suggests a pattern consistent with derivation from material of near quartz-feldspar cotectic composition. This may represent a pathway for crustal fractionation and for partial melting within the continental crust of material of potassium-rich granitic composition. Ancient basemental biotite-rich gneisses are considered to be the most probable starting material. Possible correlations of volcanism with the main tectonics of the area and of the whole Brazilian shield are discussed.

### **Zusammenfassung**

*Petrologie und Chemie der präkambrischen Alkalirhyolithe von West-Bahia  
(Brasilien)*

Die Petrologie und die Chemie der Alkalirhyolithe aus dem Westen des Staates Bahia werden untersucht. Der ursprüngliche Mineralbestand und der Pauschalchemismus sind durch Sekundärprozesse (kataklastische Metamorphose, hydrothermale Auslaugung) verändert. Der Gesamtchemismus legt ein Modell nahe, das mit der Ableitung von Material nahe der Zusammensetzung des Quarz-Feldspat-Eutektikums in Übereinstimmung steht. Das kann einen Weg für Fraktionierung in der Kruste oder für partielle Aufschmelzung von Material der Zusammensetzung eines Kali-reichen Granites innerhalb der Kruste darstellen. Biotit-reiche Gneise des alten Untergrundes werden als wahrscheinlichstes Ausgangsmaterial angesehen. Mögliche Zusammenhänge des Vulkanismus mit der hauptsächlichsten Tektonik des Gebietes und des ganzen Brasilianischen Schildes werden besprochen.

### Introduction

Potassium-rich volcanic rocks equivalent to rhyolite-rhyodacites of the calc-alkali series, are relatively rare. Such alkaline rhyolites do not appear, for example, in the alkali-potassic volcanic series, according to the classification scheme proposed by *Irvine and Baragar* (1973), but here K-rich trachytes are thought to be the possible extreme differentiation product of high-potash undersaturated magma.

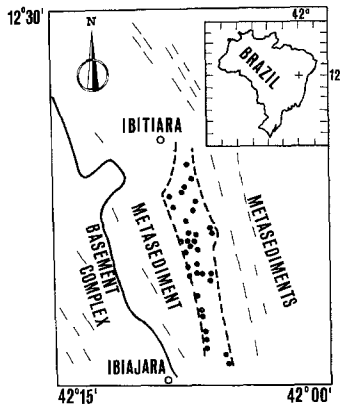


Fig. 1. Sketch map of the Ibitiara area showing approximate localities of specimen analyzed. Area contoured by broken lines: volcanic formation.

The genesis of salic alkalic volcanics may be regarded as one of the most difficult problems in igneous petrochemistry. Differentiation of a basaltic parent magma, melting within the continental crust and chemical changes related to a fluid-rich phase are the most commonly proposed genetic processes. High-potassium volcanic associations have recently aroused new interest, for they are thought to have played a role in the main crustal tectonics and therefore to throw light on significant crust-mantle interactions.

This paper studies the petrology and chemistry of Precambrian salic extrusives from Western Bahia State, Brazil. Its aim is to draw inferences regarding the possible source material for the alkaline melt and to examine some aspects of the Precambrian tectonics of part of the Brazilian shield.

### General Geology and Petrology

Salic extrusives occur in the Chapada Diamantina district, Western Bahia State, in the Ibitiara quadrangle (12°–12°30' lat. S, 42°–42°30' long. W). Volcanics form a belt 8–10 km wide extending approx. 60 km NW-SE (see the sketch map, Fig. 1). The substrate rocks in the area

consist of lower-Precambrian shield rocks and of upper-Precambrian metasediments, the latter being thought (*Shobbenhaus*, 1967) to originate from an orthogeosyncline that formed around older stabilized cratonic nuclei.

The main lithologic types present in the area consist of granite masses present in the basement formations, salic extrusives and metasediments (meta-conglomerates, arenites, phyllites, slates) all irradiated by abundant, gold-bearing, quartz veins and diabase dykes. Volcanics appear in the meta-sedimentary sequence and the main volcanic axis is concordant with the main tectonics and structures of the area. The scarcity of visible direct contacts between the extrusives and the surrounding rocks, together with a strong superimposed tectonism makes any attempt at stratigraphic reconstruction extremely problematical. *Shobbenhaus* (1967) suggested that the volcanic episode was related to an orogenic cycle attributable to the Precambrian, involving a pre-existing argillaceous-arenaceous geosynclinal series. Subsequently, the conditions would have been established for a depositional basin adjoining the continents, and later metamorphism attaining to greenschist facies conditions would have involved all the formations, causing the intense tectonization visible in particular on the extrusives. One K—Ar age determination on the volcanics (*Tavora et al.*, 1967) gives a minimum age of 390 m.y., probably dating some secondary processes which all the formations had undergone. More recent studies, however, confirm the Precambrian age of the volcanic episode.

Only by megascopic observations it is evident that various post-magmatic processes (metamorphism, hydrothermal leaching, weathering) have concurred in modifying the rocks but it is difficult to deduce from the various effects obtained which of the processes in question was dominant at any given point. Alteration tends to increase progressively from the centre to the periphery of the volcanic formation. Thus, the inner rocks are dark grey in colour and present euhedral to sub-euhedral non-oriented phenocrysts, while the outer rocks are lighter or reddish in colour and strongly foliated, with phenocrysts that are elongated and show signs of cataclastic effects. Since the degree of alteration increases progressively, any distinction between unaltered and altered rocks is quite arbitrary. In this paper it will be based on both mineralogical and chemical features.

Mineralogically, the least altered rocks contain quartz and feldspar phenocryst immersed in a microcrystalline matrix made up of an intergrowth of quartz, feldspar and magnetite with biotite, titanite and zircon as accessories.

Secondary processes have caused the nearly total disappearance

of the primitive feldspar phenocrysts and the neof ormation of abundant sericite, epidote, albite, calcite and hematite. Anorthoclase phenocrysts survive in a few samples, but they have probably undergone some structural modifications, since anorthoclase approximates to the microcline standard. The An content of the original plagioclase varies from 4 to 27%, with a tendency for it to decrease gradually from the northern to the southern part of the formation. Some strong accumulations in some rocks of secondary K-minerals (sericite, microcline) suggest that an alkali metasomatism may have occurred at least locally during metamorphism.

### Analytical Notes

Major and trace elements were determined by atomic absorption spectrometry using a Perkin Elmer mod. 403 spectrophotometer. Major element determinations were performed using the decomposition procedure suggested by *Bernas* (1968), but modified in some details. Trace elements were determined essentially following *Althaus* (1966). Precision and accuracy checks were constantly carried out on the U.S.G.S. and C.N.R.S. standard rocks.

### Chemistry

Table 1 reports major and trace element data for 34 samples of volcanics. Average contents for the various elements and element ratios were, however, calculated on the basis of only 25 unaltered or slightly altered samples, the other samples being excluded because of the strong leaching of some elements that could falsify the measured averages. The main chemistry of the rocks leads them to be classified, according to current classifications, as alkaline rhyolites or potash-rich rhyolites. The relative abundance of alkalis reflected by the values of the agpaitic index (approx. 0.85–0.95) affords evidence of an alkali trend but also of the lack of a marked alkaline character. Some bulk compositional variations (lower silica and higher Ca, Mg and iron contents) indicate that some samples present a more mafic (dacitic or rhyodacitic) composition. K-rich rhyolites, as reported above, are not included in the potassic volcanic series defined by *Irvine and Baragar* (1971), which presents K-rich trachytes as the end member. This is justified by the fact that salic K-rich extrusives are very rarely found to be genetically correlated with members of the main potassic volcanic series, the shoshonite association, characterized mainly by undersaturated rocks (K-rich basalts), the more differentiated members attaining trachyte composition (viz. the extensive literature, *Baker et al.*, 1964; *Cosgrove*, 1972; *MacKenzie and Chappel*, 1972). Nevertheless,

Table 1. *Analytical Results. Unaltered or slightly altered samples (trace elements: ppm)*

	GIB 4	GIB 7	GIB 8	GIB 9	GIB 11	GIB 12	GIB 13	GIB 14	GIB 17
SiO <sub>2</sub>	64.70	71.82	68.55	71.70	71.99	71.38	71.10	65.69	71.71
TiO <sub>2</sub>	0.33	0.50	0.52	0.42	0.24	0.38	0.32	0.33	0.53
Al <sub>2</sub> O <sub>3</sub>	12.56	12.21	12.55	12.81	12.37	12.54	12.56	13.51	12.69
Fe <sub>2</sub> O <sub>3</sub>	3.48	2.70	6.28	1.63	3.15	2.44	2.32	6.08	1.90
FeO	2.82	1.41	1.32	0.95	0.97	1.08	1.43	0.57	2.32
MnO	0.135	0.063	0.117	0.112	0.058	0.035	0.082	0.066	0.051
MgO	0.47	0.41	0.49	0.33	0.044	0.031	0.062	0.32	0.27
CaO	4.06	1.74	1.15	3.10	1.91	1.34	2.42	2.20	1.40
Na <sub>2</sub> O	3.37	3.19	4.45	2.04	3.05	2.68	2.92	4.29	2.12
K <sub>2</sub> O	4.12	5.27	3.76	5.70	5.35	7.14	4.90	3.95	6.18
H <sub>2</sub> O <sup>+</sup>	2.77	1.22	0.84	2.07	1.66	1.00	1.97	1.97	1.35
Total	98.81	100.53	100.03	100.86	100.79	100.04	100.08	98.98	100.52
Total Fe (Fe <sub>2</sub> O <sub>3</sub> )	6.61	4.26	7.74	2.68	4.23	3.64	3.91	6.71	4.47
Na <sub>2</sub> O + K <sub>2</sub> O — Al <sub>2</sub> O <sub>3</sub>	0.796	0.896	0.907	0.743	0.873	0.967	0.805	0.838	0.802
Li	7.0	19.2	21.0	12.6	8.1	2.8	4.0	4.6	22.5
Ni	9.0	11.4	18.6	9.4	16.0	10.7	8.6	13.4	13.0
Cu	26.0	77.0	11.8	7.2	9.0	9.6	18.2	83.0	8.0
Zn	108.0	204.0	87.0	56.0	50.0	35.0	64.0	83.0	76.0
Rb	38.0	230.0	94.0	166.0	264.0	150.0	61.0	112.0	305.0
Sr	35.0	30.0	46.0	51.0	30.0	28.0	52.0	58.0	22.0
Pb	6.2	140.0	6.0	0.4	1.7	3.5	10.7	13.0	2.3
K/Rb	900.0	190.0	332.0	285.0	168.0	395.0	667.0	293.0	168.0

Table 1. II: Unaltered or slightly altered samples

	GIB 18	GIB 21	GIB 23	GIB 24	GIB 25	GIB 27	GIB 30	GIB 31	GIB 33
SiO <sub>2</sub>	69.52	68.54	71.37	69.03	71.02	71.86	69.70	70.56	71.63
TiO <sub>2</sub>	0.45	0.43	0.35	0.35	0.31	0.50	0.49	0.35	0.42
Al <sub>2</sub> O <sub>3</sub>	12.46	12.09	13.71	14.35	12.49	12.74	12.81	12.37	12.95
Fe <sub>2</sub> O <sub>3</sub>	4.82	5.39	3.35	3.08	3.72	1.33	4.13	3.66	2.34
FeO	0.84	1.04	0.71	1.15	0.68	2.70	0.80	1.06	1.47
MnO	0.074	0.091	0.020	0.059	0.033	0.075	0.035	0.062	0.059
MgO	0.069	0.035	0.22	0.090	0.009	0.23	0.035	0.054	0.33
CaO	1.85	2.76	0.30	1.77	1.60	1.65	2.60	2.33	1.09
Na <sub>2</sub> O	2.90	4.56	2.55	4.25	4.47	3.40	4.04	3.91	4.03
K <sub>2</sub> O	5.07	3.69	6.37	4.47	4.41	5.35	4.56	4.95	3.59
H <sub>2</sub> O+	1.72	1.89	0.94	0.88	1.05	0.84	0.73	1.30	1.10
Total	99.77	100.63	99.89	99.48	99.79	100.67	99.92	100.60	99.01
Total Fe (Fe <sub>2</sub> O <sub>3</sub> )	5.75	6.54	4.14	4.36	4.47	4.33	5.02	4.84	3.97
Na <sub>2</sub> O + K <sub>2</sub> O Al <sub>2</sub> O <sub>3</sub>	0.822	0.949	0.809	0.823	0.971	0.892	0.903	0.952	0.811
Li	18.8	1.2	15.8	1.0	0.5	11.0	7.0	14.6	8.1
Ni	8.4	19.0	10.2	18.4	11.2	9.9	11.2	13.0	11.0
Cu	9.1	8.2	6.0	9.2	36.0	16.6	9.8	7.0	8.0
Zn	85.0	40.0	78.0	30.0	30.0	164.0	45.0	44.0	113.0
Rb	195.0	34.0	286.0	160.0	140.0	220.0	54.0	195.0	80.0
Sr	62.0	156.0	37.0	42.0	40.0	48.0	56.0	93.0	107.0
Pb	8.0	13.0	10.7	2.4	8.0	35.0	13.0	2.4	15.5
K/Rb	216.0	900.0	185.0	232.0	261.0	202.0	700.0	211.0	372.0

Table 1. III: Unaltered or slightly altered samples

	GIB 34	GIB 35	GIB 38	GIB 39	GIB 44	GIB 47	GIB 49	Averages (25 samples)
SiO <sub>2</sub>	67.62	66.37	71.98	72.49	70.64	67.06	72.35	70.01
TiO <sub>2</sub>	0.80	0.76	0.37	0.26	0.38	0.72	0.40	0.44
Al <sub>2</sub> O <sub>3</sub>	13.99	12.50	12.53	12.41	12.19	14.85	12.55	12.83
Fe <sub>2</sub> O <sub>3</sub>	2.80	6.00	2.03	2.01	3.12	2.77	3.45	3.36
FeO	2.36	2.92	0.84	1.19	0.56	2.53	0.24	1.36
MnO	0.067	0.061	0.054	0.045	0.060	0.094	0.066	0.067
MgO	0.63	0.30	0.085	0.047	0.32	0.98	0.093	0.24
CaO	1.35	2.17	1.16	0.85	1.72	1.30	1.15	1.80
Na <sub>2</sub> O	5.18	2.77	4.32	4.64	2.13	4.73	3.67	3.60
K <sub>2</sub> O	4.20	6.03	4.59	4.02	6.32	3.62	4.72	4.89
H <sub>2</sub> O+	1.38	0.62	1.08	1.09	1.53	1.74	1.26	1.33
Total	100.38	100.50	99.03	99.05	98.97	100.39	99.95	
Total Fe (Fe <sub>2</sub> O <sub>3</sub> )	5.42	9.24	2.96	3.33	3.74	5.58	3.72	4.87
$\frac{\text{Na}_2\text{O} + \text{K}_2\text{O}}{\text{Al}_2\text{O}_3}$	0.932	0.886	0.963	0.964	0.839	0.787	0.888	0.873
Li	9.6	3.7	2.8	13.0	9.7	23.2	21.2	10.5
Ni	13.4	11.8	13.0	13.0	10.2	9.6	11.0	12.1
Cu	29.5	9.2	7.0	7.2	5.0	16.8	26.0	18.4
Zn	80.0	81.0	25.0	64.0	49.0	101.0	126.0	77.0
Rb	99.0	125.0	190.0	120.0	198.0	80.0	148.0	150.0
Sr	88.0	60.0	81.0	30.0	46.0	76.0	39.0	56.0
Pb	1.7	1.7	4.5	4.5	10.7	2.4	15.5	13.3
K/Rb	352.0	401.0	200.0	278.0	265.0	373.0	265.0	352.0

Table 1. IV: Strongly altered samples

	GIB 5	GIB 6	GIB 10	GIB 19	GIB 20	GIB 22	GIB 37	GIB 40	GIB 41	GIB 42
SiO <sub>2</sub>	61.77	84.77	83.08	88.08	79.65	79.21	72.38	73.60	73.55	73.14
TiO <sub>2</sub>	0.75	0.23	0.23	0.31	0.21	0.24	0.38	0.37	0.13	0.50
Al <sub>2</sub> O <sub>3</sub>	16.66	7.51	9.34	5.62	11.75	11.17	12.22	12.87	14.93	13.13
Fe <sub>2</sub> O <sub>3</sub>	7.65	1.88	2.56	2.25	1.20	2.93	4.12	2.85	3.17	3.76
FeO	0.91	0.58	0.60	1.12	0.89	0.59	0.73	0.57	0.53	0.35
MnO	0.039	0.004	0.073	0.002	0.030	0.015	0.038	0.002	0.082	0.033
MgO	0.206	0.150	0.143	0.26	0.50	0.20	0.062	0.047	0.028	0.55
CaO	traces	traces	traces	0.10	traces	traces	0.50	traces	0.05	traces
Na <sub>2</sub> O	0.11	0.028	0.05	0.027	0.53	0.10	1.69	1.01	0.22	0.18
K <sub>2</sub> O	7.95	2.91	3.71	1.88	3.80	3.63	5.98	6.49	4.68	7.29
H <sub>2</sub> O+	3.11	1.44	1.13	1.16	1.78	1.52	1.73	1.89	2.20	2.00
Total	99.16	99.50	100.91	100.81	100.34	99.60	99.83	99.70	99.57	100.93
Total Fe (Fe <sub>2</sub> O <sub>3</sub> )	8.66	2.52	3.23	3.49	2.19	3.58	4.93	3.48	3.76	4.15
Na <sub>2</sub> O + K <sub>2</sub> O Al <sub>2</sub> O <sub>3</sub>	0.526	0.423	0.437	0.368	0.423	0.376	0.757	0.673	0.362	0.623
Li	29.5	28.0	16.2	12.0	12.2	1.2	7.0	7.3	0.6	10.2
Ni	18.2	5.2	3.0	3.4	7.1	5.0	12.0	7.6	13.4	5.6
Cu	9.4	7.0	53.0	9.0	28.0	6.0	7.0	6.0	7.0	5.0
Zn	100.0	75.0	49.0	46.0	30.0	49.0	66.0	58.0	20.0	81.0
Rb	500.0	193.0	153.0	110.0	162.0	186.0	230.0	253.0	233.0	250.0
Sr	5.0	5.0	3.0	6.0	17.0	10.0	7.0	17.0	12.0	9.0
Pb	9.4	1.1	13.0	0.4	0.8	1.1	9.4	12.0	2.5	10.3
K/Rb	132.0	125.0	201.0	142.0	194.0	162.0	216.0	213.0	166.0	242.0



it is commonly supposed (*Gill, 1972*) that magma of trachyte composition may be the immediate parent of alkaline rhyolites.

The diagram Or—Ab—An (Fig. 2A) shows the composition of the normative feldspar. Most of the samples occur at the boundary

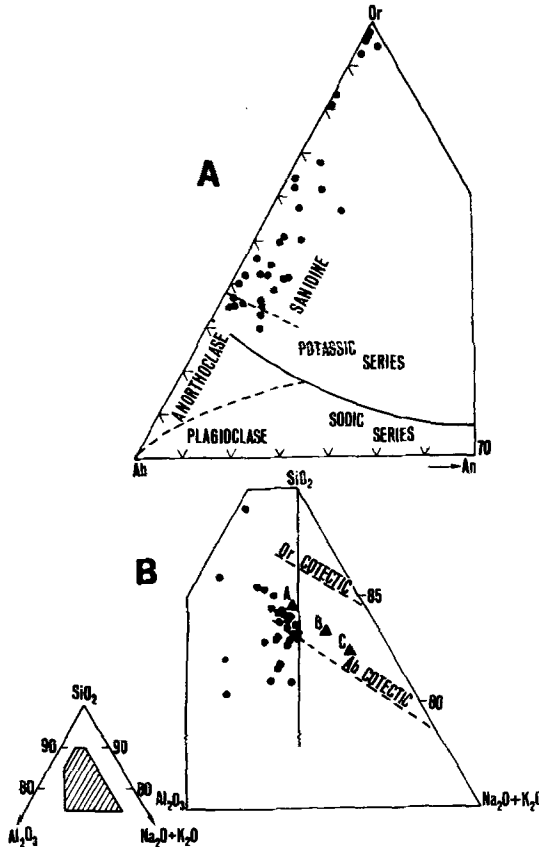


Fig. 2. (A) Or—Ab—An normative diagram. Mineral phase fields and feldspar composition in different rock series are delimited from *Girod and Lefevre (1972)* and from *Irvine and Baragar (1971)*. Solid circles: rhyolitic rocks from Bahia. (B) SiO<sub>2</sub>—Al<sub>2</sub>O<sub>3</sub>—total alkalis molecular diagram. Broken lines: albite-silica and orthoclase-silica cotectic boundaries [ $P(\text{H}_2\text{O}) = 1 \text{ kb}$ ] from *Shairer and Bowen (1955, 1956)*. Points A, B, C: quartz-feldspar minima defined by *Carmichael and MacKenzie (1963)*.

between the sanidine and anorthoclase fields plotted in accordance with *Girod and Lefevre (1972)*, as is normally the case with feldspar of salic alkaline extrusives. Samples which, on account of a low sodium content, fall outside these limits exhibit the effects of secondary pro-

cesses. They will be not considered in any further discussions regarding the chemistry, source material and formative processes of the rocks.

In view of their bulk chemistry, it is appropriate to examine variation patterns of the volcanics in terms of the system  $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ . Recalculation of these four oxides to 100 molecular percent was carried out. Fig. 2B examines the variations in silica, alumina and combined alkalis. Most of the unaltered or slightly altered samples are closely grouped within a quartz-cotectic zone defined by the field boundaries of Or-silica and Ab-silica taken from the system  $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$  and  $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$  at 1 bar. (Schairer and Bowen, 1955, 1956) and within the line marking the  $(\text{Na}_2\text{O} + \text{K}_2\text{O})/\text{Al}_2\text{O}_3$  ratio equal to unity. In addition, most of the samples fall near the quartz-feldspar minimum (point A), plotted from Bailey and MacDonald (1970), that, together with B and C minima, characterizes three sections with increasing alkalinity of the system Ab—Or—Q—Ac—Ns— $\text{H}_2\text{O}$  at 1 kb water pressure by Carmichael and MacKenzie (1963). This would suggest that these rocks, whatever their origin, approach quartz-feldspar minima compositions. Only a few of the samples (besides of course the strongly-altered silica-enriched samples) fall outside the quartz-feldspar cotectic zone. They indicate the presence of members of more mafic (rhyodacitic) composition. Similar inferences can be drawn from the quartz-albite-orthoclase normative diagram.

The bulk compositional variations of the Bahia volcanics can be illustrated by a plot of the factor  $(\frac{1}{3} \text{Si} + \text{K})-(\text{Ca} + \text{Mg})$ , called differentiation factor by El-Hinnawi et al. (1969), against main and trace constituents (Fig. 3). Potassium increases with this factor as well as with silica content. Increased alkali content with differentiation is normally encountered in alkaline volcanic series (Jakeš and Smith, 1970; Girod and Lefevre, 1972; Bauer et al., 1973). Potassium content is constantly higher than Na content, but the preponderance of K over Na is more marked in the more differentiated samples for higher amounts of K-feldspar phenocrysts in the latter. This analogous feature was found in ignimbrites (El-Hinnawi et al., 1969).

Most of the trends observed for main and trace elements (see Fig. 3) represent typical magmatic trends. Non-magmatic figures are normally due to the scattering of the strongly altered samples. Here some considerations regarding some of the most significant trace elements and element ratios will be reported.

The average rubidium content (150 ppm) conforms well with the normal values for granitic rocks, but the average K/Rb value (352) is appreciably higher than the "granite" average and than the corresponding average in rhyolitic rocks (Ewart et al., 1968). This is in

part due to some abnormally high K/Rb values caused by a certain depletion of Rb relative to K. The plot of K vs. Rb (Fig. 4) confirms this, indicating a lower coherence between the two elements than is normally found in magmatic rocks. For this reason, it is hard to ascertain whether K/Rb decreases as K increases, an observation

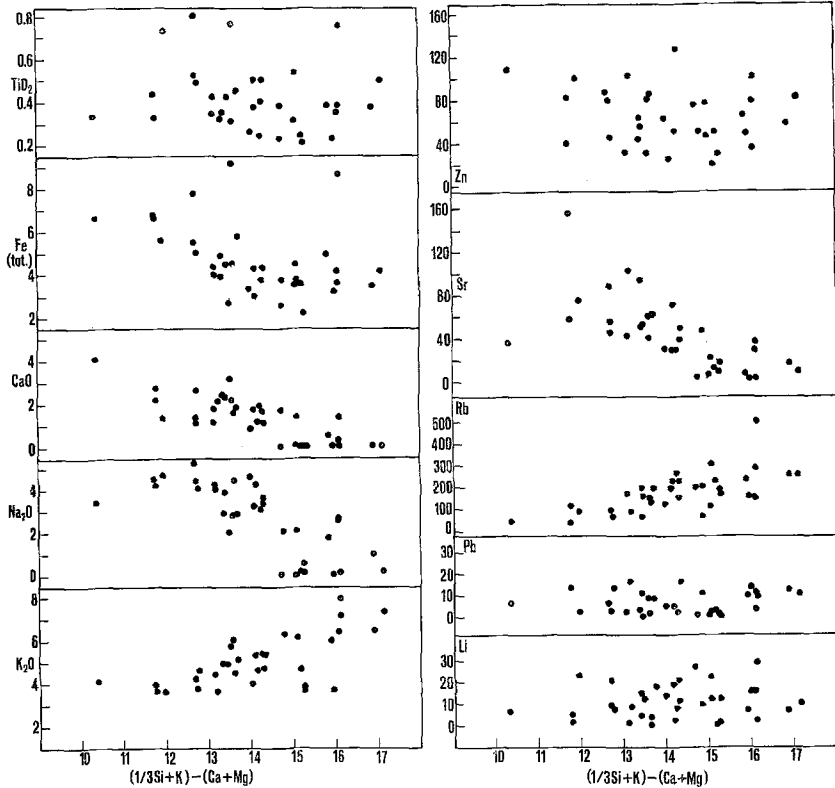


Fig. 3. Variation of the major and trace constituents as a function of the "differentiation index".

that may indicate whether the residual liquid was obtained by previous fractionation of plagioclase (*Ewart et al.*, 1968). In the case of the more altered samples, the hydrothermal process may have been responsible for the partial separation of Rb from K, for in hydrothermally-formed material Rb normally accumulates at the expense of K (see Fig. 4, the pegmatitic-hydrothermal trend—*Shaw*, 1968). The mean strontium content (56 ppm) is notably lower than in other granitic rocks, as is reflected in the extremely high Rb/Sr ratios. Two factors may have

contributed to lower the Sr levels: first, the fractionation rate at which residual liquid originated; second, postmagmatic processes (hydrothermal leaching and/or weathering). Marked depletion of Sr is visible where leaching of other elements, such as Ca, Mg and Na, has also occurred. On the other hand, progressive lowering of Sr in residual liquid undoubtedly occurs, for even in unaltered samples strontium decreases markedly as the differentiation factor increases.

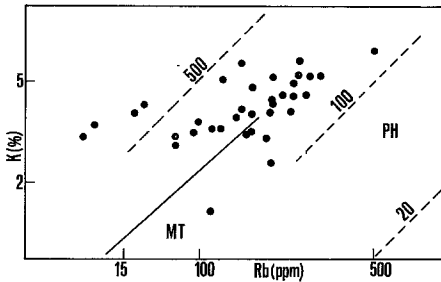


Fig. 4. Potassium content vs. rubidium content. MT line: main igneous trend, PH area: pegmatitic-hydrothermal trend (from Shaw, 1968).

Accordingly, extreme depletion of Sr in salic extrusives is normally considered as the result of protracted crystal fractionation (Weaver et al., 1972) and, more generally, of peralkaline conditions in the magma generation (Nicholls and Carmichael, 1969).

The Pb and Li abundances are especially low when compared with the "average" granite abundances (Taylor, 1964; Taylor and White, 1966), such as the values for salic extrusives of alkaline rhyolitic composition (Wedepohl, 1956; Ewart et al., 1968; El-Hinnawi et al., 1969). This is worthy of note, because lead normally tends to be concentrated in potassium-rich salic rocks entering the K-feldspars in which it diadochically replaces potassium.

Average nickel (12.1 ppm) and copper (18.4 ppm) contents are slightly in excess of normal values for granitic extrusives.

### Effects of Postmagmatic Processes

As reported above, a great part of the formation has undergone complex mineralogical transformations and abrupt changes in the chemistry because of leaching of alkalis and alkaline earths. Metamorphism under greenschist facies conditions, hydrothermal activity and probable tropical weathering have undoubtedly had their effects, but it is extremely difficult to reconstruct the sequence in which alterations may have taken place or to attribute them correctly. Meta-

morphism was surely responsible for the neoformation of sericite, albite, calcite and epidote from the primitive feldspars. In addition, some local concentration of potassium minerals seems to account for metasomatic reactions during metamorphism.

Hydrothermalism is widespread and is responsible for the abundant quartz veins that intersect extrusives and surrounding formations. Cataclastic and hydrothermal activity may be correlated with the intrusion of the granite masses present in the area, but hydrothermalism can only be correlated with greenschist facies metamorphism. The main chemical changes may have been a consequence of hydrothermal leaching, but strong tropical weathering could also have produced a similar residual silica-rich material. Leaching of Precambrian rhyolites was previously studied by *Barker and Burmester (1970)*. They found that the depletion of alkaline earths was accompanied by that of silica as a consequence of the destruction of quartz phenocrysts. This fact was interpreted as being due to the very high pH of the leaching solutions favouring silica solubility. In the rhyolites examined, the persistence of quartz crystals indicates that the leaching solutions, whatever their origin, must have had a sufficiently low pH to impede silica mobilization, as would be expected for solutions that travel, whether ascending or descending, through silicate acid rocks.

### The Genesis of the Alkaline Rhyolites

The main chemistry of the salic extrusives of Bahia suggests a pattern consistent with derivation from a quartz-feldspar or near quartz-feldspar cotectic zone in the vicinity of a quartz-minima path. This may represent a path of crystal fractionation of a more mafic magma or of increasing partial melting within the continental crust of material of alkali-rich granitic composition. The slight compositional variations may indicate that fractional crystallization has acted to some extent in differentiating the salic liquid. The production of peralkalic liquids from other melts by fractional crystallization have been investigated (*Bailey, 1964; Bailey and Schairer, 1964; Bailey and MacDonald, 1969*). Differentiating liquids which fractionate towards peraluminous minima can produce oversaturated alkali rhyolites. It is also supposed that magma of trachyte composition may be the immediate parent of alkaline rhyolites (*Gill, 1972*) but direct relationships between these rocks and other members of the potassic igneous series are not normally observed. As regards the origin of the K-rich undersaturated liquids, it has been suggested that these liquids are generated in depth (*Bell and Powell, 1969; Wright, 1971*) and are correlated to major events of continental tectonics, in general

following crustal plate collision models (*Jakeš and White, 1969; MacKenzie and Chappel, 1972; Barberi et al., 1974*). K-rich extrusives characterize newly-stabilized orogenic regions (*Joplin, 1968*) as well as areas of active island arc tectonism (*Smith, 1972*), where slabs of sialic crust sinking into the mantle have undergone partial melting involving a mica phase responsible for the high K content of the melt. For the volcanics examined, findings (geological setting, complete absence of more mafic possibly-correlated volcanics in the area or elsewhere) point to the dominance of partial melting within the crust in the production of salic alkalic magma. Many hypotheses could be proposed as regards the possible original material that underwent partial melting. Table 2 is a list, drawn up from the literature, of crustal materials considered for the production of undersaturated or saturated K-rich melts. In our opinion, any identification that rests on chemical affinities or on geological speculation regarding the possible starting material that, through partial melting, gives rise to a given liquid is extremely problematical, for large compositional convergences or divergences can be caused by a number of parameters (e.g. composition and pressure of the fluid phase, hybridizations, volatile transfers, etc.). Nevertheless, some observations (high K/Rb values and Fe, Cu and Ni contents) seem to indicate, however tentatively, that ancient basement biotite-rich gneisses, depleted in Rb with respect to K during repeated metamorphic cycles, were the most probable starting material for the Bahia volcanics.

It would be very interesting to attempt to correlate the volcanic episode with the main tectonics of the area and possibly of the whole Brazilian shield. As previously reported, *Shobbenhaus (1967)* correlated the volcanism with the evolution of a geosyncline established in the Precambrian over a limited depositional basin near a continental block. Salic volcanism would have occupied a later stage in accordance with the normal evolution of orogenic cycles (*Zaridze, 1974*). The scarcity of stratigraphic data does not enable the validity of such a reconstruction to be confirmed. The lack of age data, on the other hand, thwarts any attempt at a correlation with the major cycles (Espinhaço, Urucuaño and Brasileiro geotectonic cycles) that, according to *Almeida (1971)*, succeeded one another during the Precambrian tectonic evolution of the Bahia and Central Brazil areas. Some other facts must be considered. The ancient basement in the Bahia area is normally subdivided into two principal stable units. *Cordani (1973)* distinguishes one unit occupying Central-western Bahia (the São Francisco craton) from a more easterly unit (the Salvador craton). Since the boundaries between the two units are not yet well defined, the precise position of the volcanics relative to the two stable blocks

Table 2. *Some Interpretations for the Genesis of Potassium-Rich Magmas*

Type of rocks generated	Starting material and genetical process	Author
alkali-rich mafic lavas in general	anatexis of biotite- and hornblende-rich plutonic rocks	<i>Waters, 1955</i>
alkaline igneous suite, Eastern Uganda	melting of fenitized basement rocks	<i>King, 1965</i>
potash-rich rhyolites	K-metasomatism of calc-alkaline rhyolitic rocks	<i>Radulescu, 1966</i>
rhyolitic effusives, Central North Island, New Zealand	partial fusion of associated greywacke-argillite sequence	<i>Ewart et al., 1968</i>
alkalic rhyolitic-rhyodacitic ignimbrites, Chile	anatexis of great masses of granitic crustal material	<i>El-Hinnawi et al., 1969</i>
high-potash calc-alkaline rocks, Eastern Papua	fractional melting of amphibole- and mica-bearing eclogite	<i>Jakes and Smith, 1970</i>
potash-rich felsites, Inverness-Shire, England	partial melting of arkosic material	<i>Ridley, 1971</i>
precambrian potash-trachyte, Malvernian, England	partial melting of biotite-rich basement rocks	<i>Thorpe, 1971</i>
permian shoshonitic suite, Devon, England	partial melting of sinking slabs of oceanic phlogopite-bearing crust	<i>Cosgrove, 1972</i>
shoshonitic associations	partial melting of sialic crust in eclogite sinking into the mantle	<i>MacKenzie and Chappel, 1972</i>

is difficult to ascertain. Volcanics seem to occur in an area marginal to a continental block but, from the data available, their localization within a block (i.e. a continental nature) cannot be excluded. Precambrian volcanic manifestations of mainly rhyolitic character are widespreadly distributed over two great stable masses (the Guaporè and Guianian cratons) occupying most of the Northern Brazil, Surinam and Venezuela (*Almeida, 1967*). Some recent papers (e.g. *Issler, 1974*) stress the huge volume and the continental, anorganic and fissural character of these volcanic manifestations. In particular, in the Amazonian basin volcanic axes seem to coincide with great fault and fracture systems (*Montalvao, 1974; Oliveira et al., 1974*). The scanty data available on the petrology and chemistry of the Amazonian rhyolites together with the greater scale of the phenomena prevent parallels from being drawn with the volcanics from Bahia. Nevertheless, the very similar petrologic associations present and the almost complete lack of intermediate-mafic products, usually associated with salic volcanics, do represent points of similarity. The presence of practically only one acid cycle and the great extent of the phenomena pose puzzling problems regarding its relationship with the main continental tectonic and regarding the origin of the magma.

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