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PETROCHEMISTRY OF THE ROCKS FROM BABAJI AREA, A PART OF THE AMBELA GRANITIC COMPLEX, BUNER, NORTHERN PAKISTAN

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ABSTRACT

Geological mapping covering 50km² around Babaji in Buner, shows that the area comprises of syenites, quartz-syenites and granites. The rocks are distinguished on the basis of field and petrographic observations. Petrochemically (19 analyses) the Babaji rocks are comagmatic and have the characteristics of an extensional type of plutonic suite, associated with rifting. There is a close correlation of available chemical indices of the studied suite with similar rocks elsewhere in the world.

INTRODUCTION

Syenites, quartz-syenites and granites are the major rock types in the Babaji area of Buner, Swat District. These rocks extend from Bagh Banda in the west to Kuliari village in the east (Fig. 1). The Babaji rocks constitute the northern portion of the Ambela Granitic Complex and have sharp contacts with metacalcareous rocks towards north. The constituent rocks from the studied area are possibly of Early Tertiary age (Siddiqui *et al.*, 1968; Kempe, in press), intruding the Lower Swat-Buner Schistose group of Palaeozoic age (Davies *et al.*, 1963).

The region was first geologically investigated by Martin *et al.* (1962). Later, Siddiqui (1965) and Siddiqui *et al.* (1968) investigated the Babaji syenites and considered them to be comagmatic with Koga syenites. Kempe and Jan (1970) Kempe (1973) included the Ambela Complex in their alkaline igneous province. East and west of the Complex, there are abundant occurrences of intimately associated contemporary igneous rocks in an arcuate belt which extends from Mansehra and Tarbela in the east through Utla, Ambela and Warsak to Khyber Agency in the west (Kempe and Jan, 1980).

This paper presents a detailed account of the petrography and geochemistry of the three major rock types, i.e. syenites, quartz-syenites and granites from the

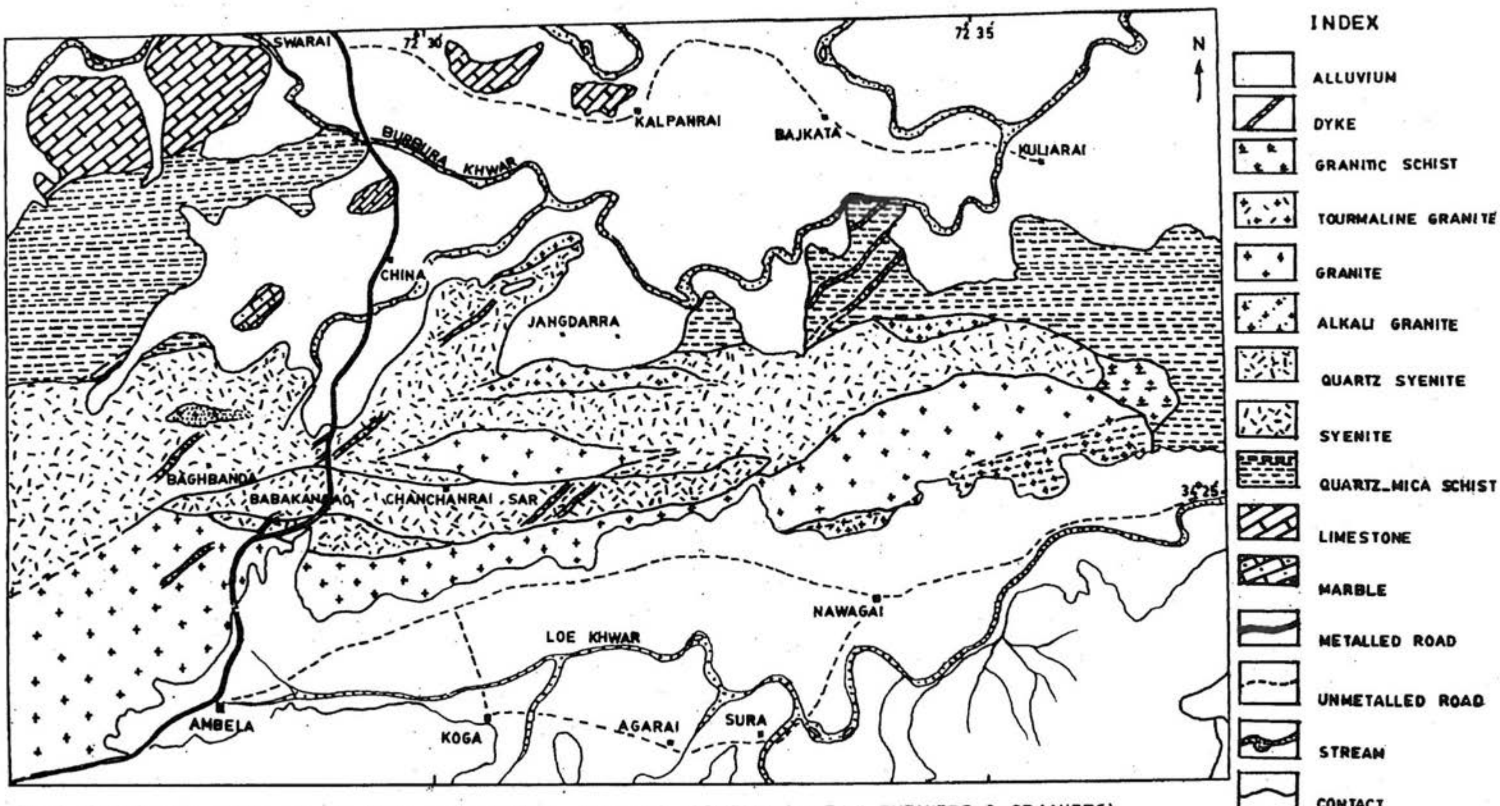

FIG.1. GEOLOGICAL MAP OF A PART OF AMBELA GRANITIC COMPLEX (BABAJI SYENITES & GRANITES), BUNER, N.W.F.P., PAKISTAN

0 1 2 3 Miles

PREPARED BY M. RAFIQ, MUJEEB-UR-RAHMAN, M. IHSAN

Babaji area of the complex. A geologic map has been prepared (Fig. 1) on toposheet No. 43B/11 with 1:50,000 scale. One hundred and twenty hand specimens were cut in thin sections and studied under microscope, 19 were selected for chemical analyses. I.U.G.S. system of nomenclature has been adopted for classification.

PETROGRAPHY

Three major rock types within the studied portion can easily be distinguished petrographically and in hand specimens on the basis of their colour index and texture.

Syenites

These are mostly composed of alkali feldspars (perthite≃35%, orthoclase≃22% and microcline≃8%) and have been previously described as the Babaji Syenites (Siddiqui *et al.,* 1968). Plagioclase (An_{10}–An_{25}) in thin sections constitutes approximately 20% by volume. Most of the feldspar grains are fresh, but alteration to sericite and epidote is not uncommon. Quartz is mostly concentrated around the perthite grains. Among the dark coloured constituents, hornblende is much more than biotite and pyroxene (aegirine). The common accessories are sphene, epidote, zircon, apatite and ore minerals.

Quartz-Syenites

These rocks are medium- to coarse-grained and mostly weathered with the development of a yellowish colour in hand specimens. In thin sections, alteration of orthoclase to sericite and clay minerals, zoning of plagioclase and graphic intergrowth around some of the alkali feldspar grains is conspicuous. Biotite is the common accessory mineral. Muscovite, sphene, epidote, amphibole, zircon, apatite and ore grains are also present in traces.

Granites

These are coarse-grained rocks showing yellowish colour on weathered surface. The alkali feldspars (perthite orthoclase and microcline) constitute up to 60% of these rocks. The quartz is present up to approximately 20% by volume. The plagioclose (An_{10}–An_{20}) grains exhibit the development of white mica due to chemical weathering. Biotite is the dominant of the ferromagnesian minerals which make up to 5% of the rocks. Tourmaline, muscovite, sphene, epidote, apatite, garnet, zircon and ore minerals are among the common accessories.

CHEMISTRY

Major element analyses and CIPW norms of 19 rock samples from the Babaji area are presented in Table 1, 2 and 3. SiO_2 and Al_2O_3 have been determined gravimetrically, FeO by volumetric method and the remaining oxides by atomic absorption spectrophotometer. The data is presented diagrammatically in a series of plots and is also compared with the equivalent rock compositions from the alkaline igneous province to the northwest of Peshawar.

TABLE 1. CHEMICAL ANALYSES OF SYENITES FROM BABAJI AREA.

	AS1	AS2	AS3	AVERAGE
SiO_2	60.83	60.92	61.59	61.11
TiO_2	0.76	0.03	0.32	0.37
Al_2O_3	18.49	20.46	18.32	19.09
Fe_2O_3	3.50	2.71	3.12	3.11
FeO	0.30	1.31	0.94	0.85
MnO	0.11	0.15	0.15	0.09
MgO	0.04	0.44	0.65	0.38
CaO	2.48	1.75	1.95	2.06
Na_2O	5.78	5.02	5.81	5.54
K_2O	6.42	6.10	6.01	6.18
P_2O_5	0.04	0.21	0.12	0.12
H_2O^-	0.07	0.03	0.00	0.03
Ig. Loss	0.65	0.69	0.58	0.64
TOTAL	99.47	99.82	99.43	99.57
		C.I.P.W. NORMS		
Qz	0.40	4.45	0.42	1.75
Or	37.85	36.18	35.63	36.55
Ab	46.67	42.48	49.30	46.15
An	5.56	6.96	6.12	6.21
Ac	—	—	—	—
C	—	3.06	—	1.02
Wo	2.22	—	—	0.74
Di	0.22	—	2.17	0.80
Hy	—	1.50	0.60	0.70
Mt	—	3.94	2.08	2.01
Ap	—	0.34	0.34	0.23
Il	0.76	—	0.61	0.45
Hm	3.51	—	1.75	1.76

AS1—AS3 : Syenites, Babaji area. Analyst : M. Tahir Shah

TABLE 2. CHEMICAL ANALYSES OF QUARTZ-SYENITES FROM BABAJI AREA.

	AQ1	AQ2	AQ3	AQ4	AQ5	AQ6	AQ7	AQ8	AQ9	AQ10	AQ11	Average
SiO_2	65.43	65.57	66.21	66.32	66.32	66.42	66.49	66.72	66 85	66.92	67.59	66.44
TiO_2	0.83	0.13	0.42	0.00	0.21	0.22	0.21	0.43	0.25	0.22	0.51	0.31
Al_2O_3	16.23	16.76	16.62	17.76	16.31	15.76	15.42	16.39	15.98	16.22	16.88	16 39
Fe_2O_3	2.26	2.32	2.31	2.68	2.67	2.72	2.95	2.80	0.56	2.47	2.42	2.38
FeO	0.82	0.82	1.61	0.26	0.75	0.48	8.86	1.28	2.07	0.71	0.07	0.88
MnO	0.16	0.17	0.00	0.04	0.02	0.05	0.10	0.03	0.02	0.10	0.00	0.07
MgO	1.18	0.56	0.31	0.04	0.22	0.05	0.41	0.24	0.36	0.26	0.01	0.33
CaO	1.46	0.86	0.81	0.47	0.46	0.45	1.41	0.65	0.73	0.55	0.59	0.77
Na_2O	4.31	4.76	4.94	4.98	5.11	4.84	4.93	4.90	4.80	5.03	4.37	4.81
K_2O	5.43	5.82	5.45	6.34	6.60	5.92	5.26	5.40	6.61	5.47	5.93	5.84
P_2O_5	0.34	0.03	0.21	0.20	0.12	0.06	0.23	0.05	0.03	0.00	0.26	0.14
H_2O^-	0.11	0.17	0.10	0.09	0.08	0.16	0.10	0.03	0.07	0.08	0.04	0.09
Ig. Loss	0.76	1.00	0.48	0.43	0.61	0.50	0.70	0.51	0.79	0.97	0.73	0.68
TOTAL	99.32	98.97	99.47	99.61	99.48	97.63	99.07	99.43	99.16	99.00	99.40	99.13
					C. I. P. W. NORMS							
Qz	15.14	12.80	14.42	12.62	10.63	15.44	16.16	15.92	10.57	15.26	17.84	14.25
Or	32.29	34.51	31.73	37.29	38.96	35.07	31.77	31.73	38.96	32.29	35.01	34.51
Ab	36.71	40.38	41.95	41.95	43.00	40.90	41.95	41.43	40.38	42.48	37.23	40.76
An	5.56	4.17	3.89	1.39	1.39	0.28	4.17	3.34	2.78	2.78	3.06	2.98
Ac	—	—	—	—	—	—	—	—	—	—	—	—
C	1.12	1.02	1.22	2.24	0.41	1.02	—	1.33	—	1.02	2.14	1.05
Wo	—	—	—	—	—	—	—	—	—	—	—	—
Di	—	—	—	—	—	—	0.87	—	0.77	—	—	—
Hy	2.91	1.41	1.33	0.10	0.50	0.10	0.61	0.60	0.69	0.60	0.10	1.09
Mt	0.69	2.55	3.24	1.16	1.85	1.16	2.32	3.01	0.93	1.85	—	1.70
Ap	0.67	—	0.34	0.34	0.34	—	0.67	—	—	—	0.67	0.21
Il	1.52	0.30	0.76	—	0.30	0.46	0.45	0.76	0.46	0.46	0.15	0.51
Hm	1.76	0.65	—	1.92	1.44	1.92	1.28	0.80	—	1.12	2.40	1.21
Ru	—	—	—	—	—	—	—	—	—	—	0.40	0.04

AQ1—AQ11 : Quartz-syenites, Babaji area. Analyst : M. Tahir Shah

TABLE 3. CHEMICAL ANALYSES OF BABAJI GRANITES COMPARED TO THOSE OF WARSAK, SHAHBAZGARHI AND MALAKAND.

	AG1	AG2	AG3	AG4	AG5	Average	3	4	5
SiO_2	72.62	73.08	74.89	74.94	74.99	74.10	74.16	73.98	70.68
TiO_2	0.22	0.07	0.82	0.31	0.84	0.45	0.42	0.40	0.13
Al_2O_3	11.58	13.41	13.70	13.17	13.92	13.16	11.86	11.45	15.63
Fe_2O_3	0.71	1.75	0.50	0.12	0.23	0.66	2.72	2.48	1.17
FeO	2.16	0.21	0.12	0.90	—	0.68	1.15	0.90	0.29
MnO	0.05	0.01	0.02	0.01	0.01	0.02	0.19	0.19	0.00
MgO	0.38	0.29	0.00	0.01	0.67	0.27	0.14	0.44	0.81
CaO	1.02	0.80	1.56	0.47	0.57	0.88	0.38	0.18	1.84
Na_2O	4.62	3.25	2.25	3.81	2.79	3.34	4.74	4.54	5.44
K_2O	5.51	5.60	4.12	4.96	4.43	4.92	4.32	4.72	4.25
P_2O_5	0.16	0.06	0.78	0.13	0.11	0.25	0.02	0.03	0.02
H_2O^-	0.03	0.11	0.03	0.11	0.07	0.06	0.08	0.00	0.05
Ig. Loss	0.89	0.56	0.51	0.49	0.72	0.63	0.08	0.34	0.15
TOTAL	99.95	99.20	99.30	99.43	99.35	99.43	100.26	99.05	100.61

C. I. P. W. NORMS

	AG1	AG2	AG3	AG4	AG5	Average	3	4	5
Qz	26.55	30.94	43.44	32.80	38.93	34.53	30.04	29.68	18.66
Or	32.29	32.84	24.49	29.50	26.16	29.06	25.53	27.90	25.12
Ab	29.36	27.27	18.88	31.99	23.60	26.22	36.96	32.62	46.63
An	—	3.89	3.06	1.39	1.94	2.06	—	—	4.45
Ns	1.83	—	—	—	—	0.37	—	—	—
Ac	1.85	—	—	—	—	0.37	2.77	5.10	—
C	—	0.51	4.49	1.02	3.87	1.98	—	—	—
Wo	—	—	—	—	—	—	0.05	—	—
Di	3.61	—	—	—	—	0.72	1.35	0.57	3.54
Hy	2.48	0.70	—	0.92	1.71	1.16	—	1.57	0.38
Mt	—	0.46	—	0.23	—	0.14	2.55	1.04	0.56
Ap	0.34	—	1.63	0.33	0.33	0.54	0.05	0.07	0.05
Il	0.46	0.10	0.30	0.61	—	0.29	0.80	0.76	0.25
Hm	—	1.44	0.48	—	0.16	0.42	—	—	1.39
Ru	—	—	0.64	—	0.88	0.30	—	—	—

Analyst : M. Tahir Shah

AG1—AG5 : Granites, Babaji area.

3 : Aegirine-riebeckite granite 49/453, Mulagori road S of Warsak (Coulson. 1936); anal. E. Spencer and K.B. Sen; for comparison.

4 : Aegirine-riebeckite porphyritic microgranite, Shahbazgarhi (Kempe, in press); anal. C.J. Elliott. V.K. Din and A.J. Easton; for comparison.

5 : Granite, Malakand (Chaudhry *et al.*, 1976); anal. M. N. Chaudhry; for comparison.

The rocks are mostly peraluminous ($Al_2O_3 > CaO + Na_2O + K_2O$) characterized by the appearance of corundum in the norms of 15 analyses. Sample No. AGI (granite) is unique in composition by having 1.8% each of sodium metasilicate and acmite. Granite AG3 has comparatively higher CaO and P_2O_5 due to a higher quantity of apatite. The syenite ASI also has a greater amount of CaO which has been accommodated in the formation of wollastonite in the norms. Sample No. AQ11, AG3 and AG5 have rutile in the norms which is due to their excess TiO_2 over FeO.

Table 3 compares the analyses of the Babaji granites with equivalent rocks from the other exposures in the alkaline igneous belt. Chemically the Babaji granites are matching very well with the granites of Warsak (Coulson, 1936) and Shahbazgarhi (Kempe, in press). However, the studied granites have lower values of Fe_2O_3 + FeO. The Malakand granites (Chaudhry *et al.*, 1976) are comparatively lower in SiO_2 and slightly higher in Al_2O_3 .

Figure 2 is the classification scheme proposed by Le Fort and Debon (in press for the common plutonic igneous rocks based on their chemistry. Analyses AS1, AS2 and AS3 plot in the area outlined for syenites; AG1, AG2, AG3, AG4 and AG5 in the granite field and the rest of the samples in the area defined for quartz-syenites. The nomenclature of rocks from the studied suite, on the basis of

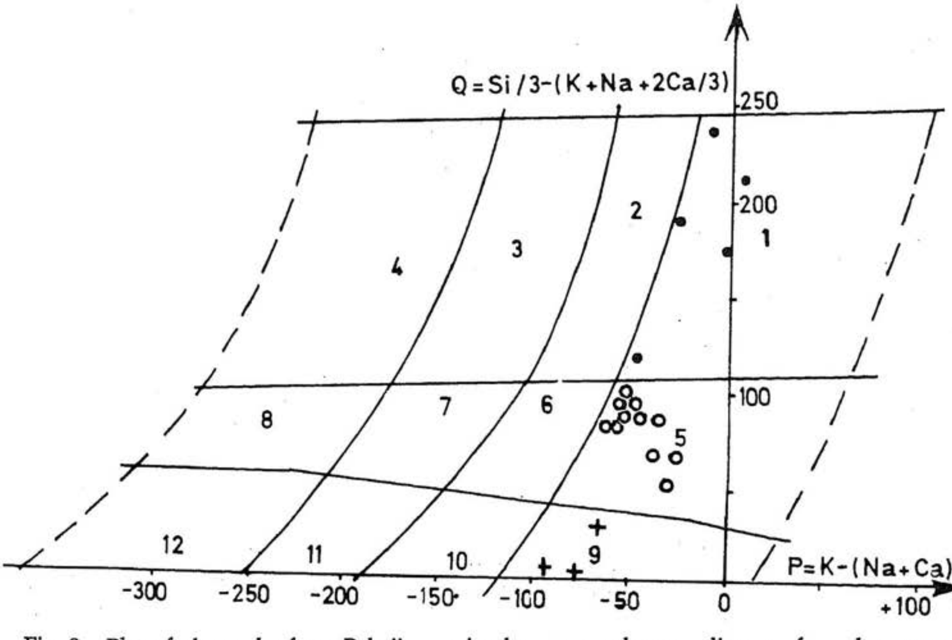

Fig. 2. Plot of the rocks from Babaji area in the nomenclature diagram for the common plutonic rocks (after Le Fort and Debon, in press). Pluses indicate syenites, open circles quartz-syenites and filled circles are granites of the area. The fields are: (1) Granites; (2) Adamellite; (3) Granodiorite; (4) Tonalite (trondhjemite); (5) Quartz syenite; (6) Quartz-monzonite; (7) Quartz-monzodiorite; (8) Quartz-diorite/gabbro/anorthosite; (9) Monzonite; (10) Monzogabbro; (11) Gabbro/diorite/anorthosite.

their chemical composition, is in striking coincidence with that of the Streckeisen's (1975) classification based on the modal composition.

On the K_2O *vs.* SiO_2 diagram (Fig. 3) of Coleman and Peterman (1975) the data points of granites and some quartz-syenites plot in the field of continental granophyres. Petro *et al.* (1979) in a plot of CaO/Na_2O+K_2O ***vs.*** SiO_2 identified two distinct areas, each representing plutonic rocks developed within the extensional (e.g. British Isles, Iceland, E. Greenland) and compressional (e.g. Sierra Nevada Batholiths) types of environment. The analysed samples from the studied suite are

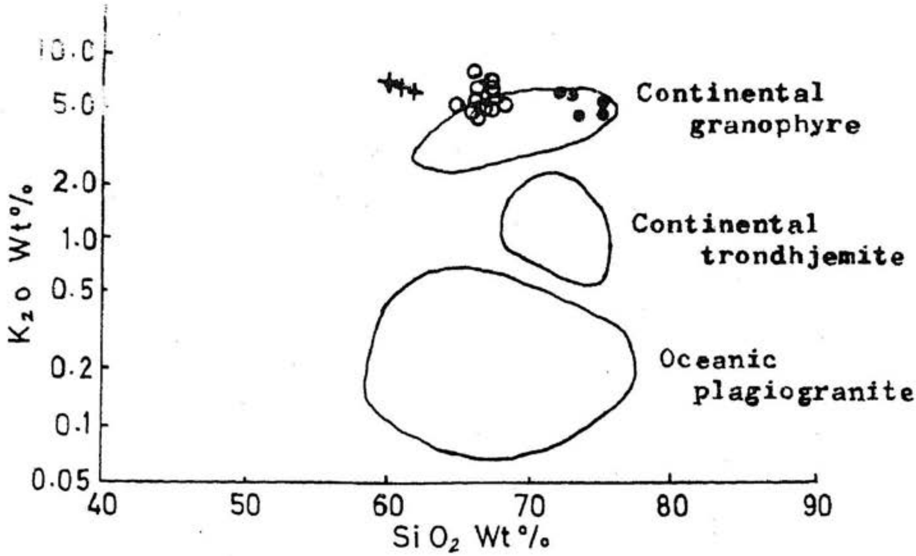

Fig. 3. SiO_2/K_2O diagram for Babaji rocks. The field of other rock suites are from Coleman and Peterman (1975). Symbols as for Fig. 2.

mostly confined to the extensional type of environment as shown in Figure 4. Table 4 compares average chemical parameters of the Babaji granites with granites originated both in the extensional and compressional type of environments elsewhere in the world. The analysed data is in best concordance with extensional type of plutonic suite.

DISCUSSION

The major element oxides *vs.* SiO_2 variation diagrams for the rocks of Babaji area (Fig. 5) exhibit a transition from syenites to granites. The compositional discontinuity between SiO_2 = 62–65% and 68–73% is probably due to an incomplete sampling. There is decrease of Al_2O_3, $FeO + Fe_2O_3$, Na_2O, K_2O and CaO with increase of SiO_2, signifying their genetic relationship. Similar behaviour is distinct on the plot of normative CIPW composition of the studied rocks in Q–Ab–Or system (Fig. 6). This suggests the control of their composition by fractional crystallization. The analyses project along the alkali feldspar join and

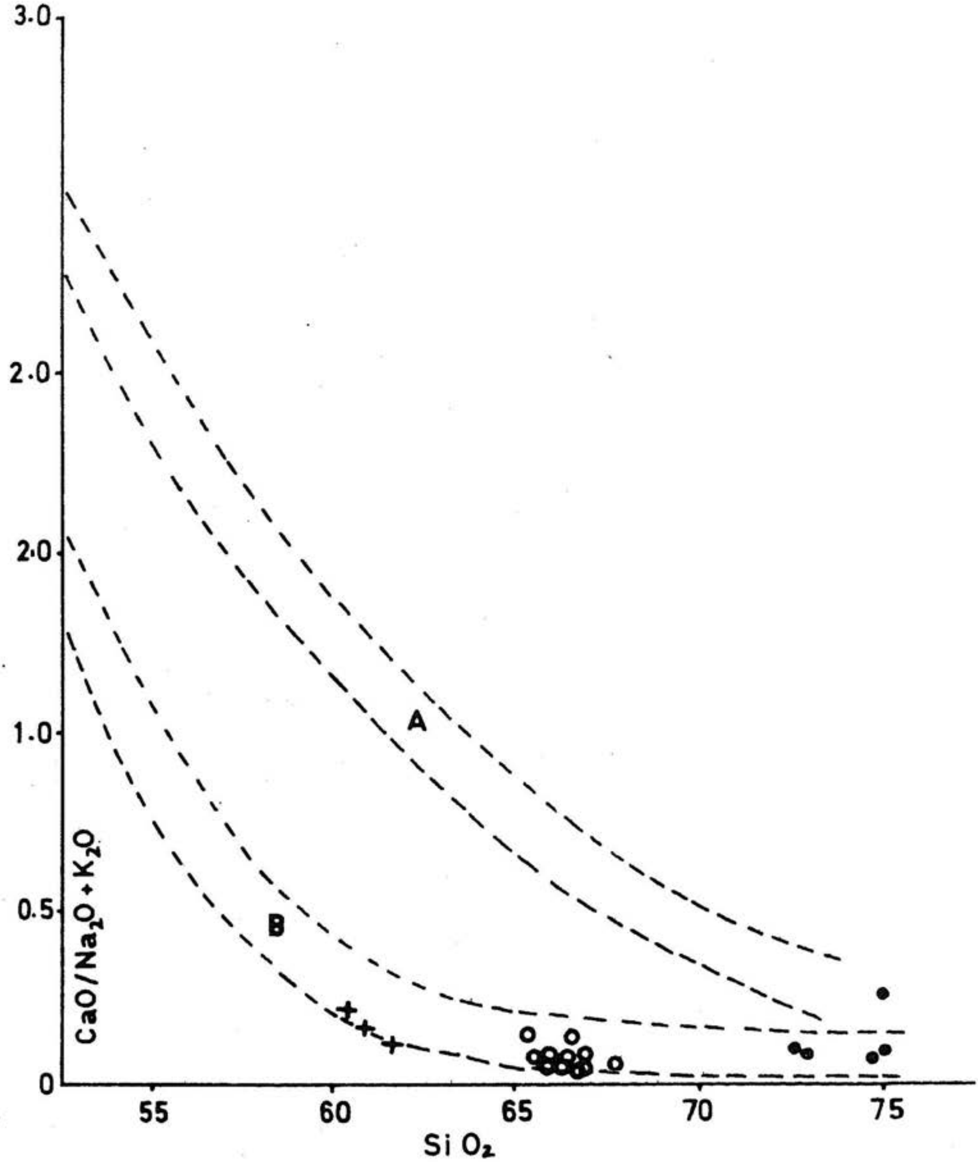

Fig. 4. $CaO/Na_2O + K_2O$ *vs*. SiO_2 plot for the Babaji rocks. A and B are respectively the general trends of plutonic rocks for compressional and extensional type of environments and are adopted from a great number of analyses plotted by Petro *et al.* (1980). Symbols as in Fig. 2.

terminate near the ternary minimum. However. the normative composition of samples AG1 and AG5, due to a considerable alteration of feldspar, plot away from the ternary minimum towards the quartz-rich side of the ternary system.

TABLE 4. COMPARISON OF GRANITES FROM EXTENSIONAL AND COMPRESSIONAL ENVIRONMENT WITH THOSE OF BABAJI AREA.

	Extensional		Compressional		
	British Isles	Iceland	Alaska batholiths	S-California batholiths	Babaji Granites (Pakistan)
DI	88.87	91.97	83.10	83.34	89.81
Al_2O_3	13.34	13.23	14.90	13.95	13.16
Fe_2O_3	1.23	1.90	0.73	1.14	0.66
FeO	1.97	0.79	1.13	1.56	0.68
MgO	0.31	0.22	0.52	0.54	0.27
CaO	1.24	0.86	2.40	2.22	0.88
Na_2O	3.79	4.35	4.09	3.53	3.34
K_2O	4.78	4.08	2.62	3.41	4.92
Alkalies	8.57	8.40	6.68	6.91	8.27
$CaO/(Na_2+K_2O)$	0.152	0.104	0.382	0.342	0.114

Average chemical data of granites from extensional and compressional 'type' British Isles, Iceland, Alaska batholiths, S-California batholiths (Petro *et al.*, 1979) and of Babaji area (this paper).

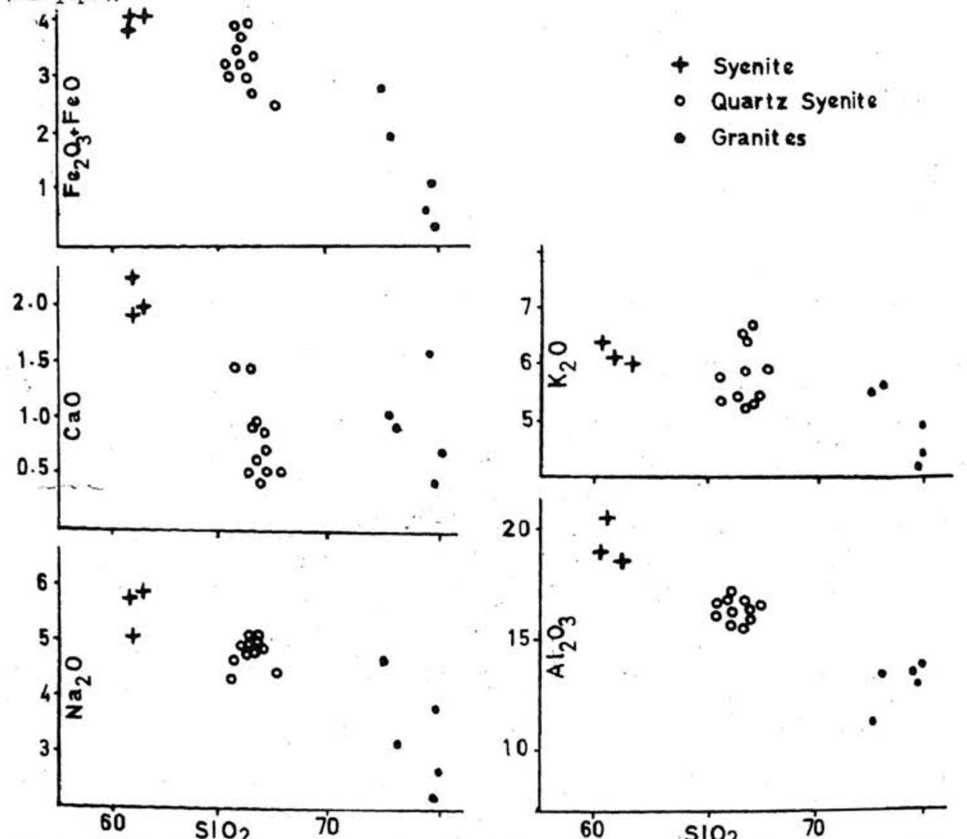

Fig 5. Major oxide percentages plotted against SiO_2 for the rocks from Babaji area. Symbols as for Fig. 2.

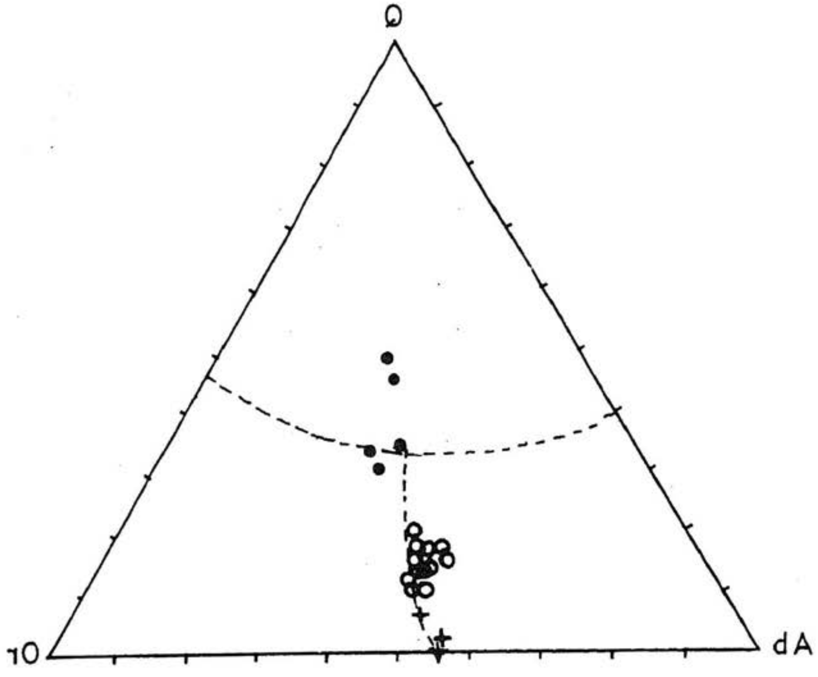

Fig. 6. Composition in terms of CIPW normative Q—Ab—Or of the chemical analyses from Table 1, 2 and 3. Boundary curve for $P_{H_2O} \sim$ 1000b is plotted for comparison (after Tuttle and Bowen. 1958). Symbols as for Fig. 2.

The geochemical parameters of the Babaji rocks suggest that they may represent a typical extensional or release-type of plutonic suite, associated with rifting. This extensional type of environment probably was produced during 50–55my ago, when the rapid rate of spreading of Indian mass was suddenly subsided due to its initial contact with Eurasia (Powell and Conaghan, 1973, 1975). Age evidence of 50my for Koga Syenites (Kempe, 1973) is in accordance with paleomagnetic data.

As alkaline rocks the world over are mostly associated with rifting (cf. Sorensen, 1974; Smith *et al.*, 1977; Bailey, 1978; Tayler *et al.*, 1980; Radian *et al.*, 1981), the Babaji rocks are also considered to have originated in rift-related environments. They might have been derived from an (alkaline) basaltic or trachytic magma (cf. Kempe, 1973), however, not enough research has been carried out in this regard.

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