Alkaline basic intrusives of Elchuru, Prakasam District, Andhra Pradesh, India

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Abstract. The igneous alkaline rocks at Elchuru start from a parent ijolite-melteigite association to basic malignite, melalusitanite and shonkinite followed by nepheline syenites and then biotite lamprophyres (as dykes) at the waning phase of the evolutionary course of the complex. The distinct alkalinity of the rocks is manifested by the development of modal nepheline and calcic amphibole (kaersutite). For both the basic rocks, *i.e.* alkali gabbro and biotite lamprophyre, the percentages of normative nepheline are always higher than modal nepheline, indicating silica deficiency and alkali enrichment of the mafics. It is evident from detailed petrological and geochemical studies that the two basic members are very much akin to each other and there is no major deviation in their bulk chemistry.

Keywords. Alkaline complex; ijolite-melteigite; malignite; melalusitanite; biotite lamprophyre.

1. Introduction

The Elchuru alkaline intrusion (16° 05' N: 79° 55' E) is an arcuate ring complex (figure 1) outcropping in the Eastern Ghats high grade metamorphic series (Bose and Nag 1980; Nag *et al* 1982; Nag and Chakravorty 1983) with abundant development of khondalites, hypersthene bearing granulites and gneisses, anorthosites, granite-gneisses, calc-granulites, quartzites and migmatites (Perraju *et al* 1979). These rocks have been variously dated by different workers as ranging from 3000–1000 Ma (Nag 1983), indicating a complex history for the Eastern Ghats, largely in the Archeans. The close spatial and temporal relationships along with limited radiometric age data on different alkaline plutons of the Eastern Ghats belt, suggest a probable Proterozoic alkaline magmatism (Sarkar 1968; Deans and Powell 1968; Crawford 1969; Subba Rao 1971; Bose 1972; Ray and Bose 1975; Moralev *et al* 1975), emplaced along deep-seated regional fractures across the high grade host rocks, particularly at Tamil Nadu (Grady 1971; Borodin *et al* 1971; Srinivasan 1973, 1977; Subramaniam *et al* 1978). The Elchuru alkaline complex, being a part of Eastern Ghats alkalic episode, is made up of a series of rock types ranging from ijolite-melteigite to alkali gabbro (represented by malignite, melalusitanite and shonkinite) and then to hypersolvus and subsolvus nepheline syenites which are penetrated by late stage biotite lamprophyre dykes. The petrography, mineralogy, geochemistry and modal content of these rocks have been studied to develop a model of the magmatic evolution of the complex. It is pertinent to mention here that the ijolite-melteigite association at Elchuru is a very recent finding (through detailed mapping on 16" = 1 mile scale) apart from alkaline gabbros as reported earlier (Madhavan and Leelanandam 1979; Nag 1979; Bose and

Figure 1. Geological map of Elchuru alkaline complex, Prakasam District, Andhra Pradesh. For inset map: 1. Koraput, Orissa; 2. Kunavaram, Andhra Pradesh; 3. Elchuru, Andhra Pradesh; 4. Sivamalai, Tamil Nadu. Cd—Cuddapah basin.

Nag 1980). An extensive geochemical and petrological account on ijolite-melteigites at Elchuru is discussed elsewhere (Nag 1983).

The purpose of the present paper is to test, using Student's *t*-statistic, whether there is statistically significant difference in modal contents or major and trace element contents and elemental ratios of the early phase alkali gabbros and the biotite lamprophyres. In all instances the null hypothesis was satisfied at the 1% confidence suggesting that both rock groups were derived from the same population.

2. Method of study

Six samples from alkali gabbro and four from biotite lamprophyre were selected for chemical analyses and their modal contents are presented in table 1. Major elements were analysed by rapid method (Shapiro and Brannock 1962) using USGS standards GSP-1 and BCR-1 for countercheck of precision and accuracy of results. Total alkalis were determined by flame photometric technique. The samples were analysed at the Geological Laboratory, Presidency College, Calcutta. Trace elements of both the rock-members were analysed using a Philips PW 1410 Universal vacuum x-ray spectrometer at the University of Windsor, Ontario, Canada. Compton scatter peaks were measured for each sample, for USGS standard rock powders W-1, AGV-1, GSP-1

Table 1. Modal data for alkaline basic rocks of Elchuru, Andhra Pradesh, India

Serial Numbers	Alkali gabbro						Biotite lamprophyre			
	1	2	3	4	5	6	7	8	9	10
Clinopyroxene	12.37	32.11	5.28	26.10	13.60	3.92	14.36	27.24	38.30	41.00
Amphibole	28.13	—	46.37	5.72	1.24	28.12	1.23	—	—	—
Biotite	9.76	46.86	14.04	38.80	50.73	19.01	51.70	41.17	47.90	51.00
Alkali feldspar	31.81	17.44	24.76	17.43	31.25	43.80	18.50	36.52	8.50	8.00
Nepheline	14.16	2.90	8.36	6.00	—	3.60	1.17	5.95	4.40	—
Apatite	2.91	0.42	0.48	1.25	—	1.07	0.22	1.05	—	—
Calcite	0.67	0.56	0.69	0.71	3.18	0.29	0.41	0.69	0.99	—
Sphene	—	—	—	3.57	—	—	—	—	—	—
Opaque	0.19	—	—	0.40	—	0.19	0.63	0.26	—	—
Colour index	53.97	79.95	66.88	76.53	68.75	52.60	68.55	70.41	87.19	92.00

and G-2, and for pure quartz on both Cr and Mo target tubes. From this data mass absorption values were determined for each sample (Turek *et al* 1977). The mass absorption values derived from the measurements using Mo tube were used to correct the analyses of Rb and Sr. The mass absorption values derived from the Cr tube measurement were used to correct the analysis of Ba.

3. Discussion

The basic malignite, melalusitanite and shonkinite are generally made up of coarse-grained subhedral minerals, grading into each other according to variation in mineralogical proportions (Streckeisen 1973). The biotite lamprophyres are fine-grained glomeroporphyritic rocks containing clinopyroxene phenocrysts. The pyroxenes in the alkaline gabbros are ferrosalite ($\text{Wo}_{54}\text{Fs}_{26}\text{En}_{20}$) and those in the biotite lamprophyres are salite ($\text{Wo}_{45}\text{Fs}_{16}\text{En}_{39}$). Both the basic rocks contain calcic amphibole (kaersutitic; Leake 1978) and Fe-Ti biotites. Microperthitic and cryptoperthitic orthoclase occur in the early basic rocks whereas the feldspar is mesoperthite orthoclase in biotite lamprophyre.

Plots of $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ -CaO-MgO-(FeO + Fe_2O_3) of alkali gabbros and biotite lamprophyres show no significant chemical differences (figure 2) between the two rock types, which also have similar Fe/Mg ratio. The ratio $\text{TiO}_2 \times 100 / (\text{FeO} + \text{Fe}_2\text{O}_3)$ when plotted against TiO_2 (wt%) shows that the combined effects of Fe-Ti do not widely differ in early and late stage magmatic events (figure 3). The ratio $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ (molecular proportions) being always less than 1 ranges from 0.83 to 0.93 for basic malignite, melalusitanite and shonkinite and 0.63 to 1.00 for biotite lamprophyres (table 2).

Geochemical studies reveal that the mean K₂O, Rb, Ba contents and K/Rb ratios of the early basic rocks (5.30%, 116 ppm, 2416 ppm and 395.65 respectively) and biotite lamprophyres (5.13%, 135 ppm, 2322 ppm and 336.13 respectively) are very similar. Average CaO contents show depletion in lamprophyres (8.23%) compared to the gabbroic member (9.52%). Strontium shows no significant difference being 1258 ppm and 1204 ppm respectively. The average ratios Rb/Sr and Ba/Sr are in accordance with their similar magmatic character showing highly significant results at 1% confi-

Table 2. Chemical analyses and cnpw Norms of alkaline basic rocks of Elchuru, Andhra Pradesh, India.

Serial Numbers	Alkali gabbro					Biotite lamprophyre				
	1	2	3	4	5	6	7	8	9	10
SiO ₂	45.92	45.71	47.81				45.20	45.54	45.83	44.34
TiO ₂	3.02	2.22	2.55				1.46	2.72	2.55	2.34
Al ₂ O ₃	17.02	12.02	13.54				17.52	14.80	12.08	12.44
Fe ₂ O ₃	0.62	4.12	4.29				1.37	4.59	2.07	5.40
FeO	7.75	7.18	7.75				6.89	6.90	7.03	6.48
MnO	0.26	1.08	1.13				0.26	1.07	0.70	0.04
MgO	4.55	7.70	4.20				8.19	5.01	8.51	9.73
CaO	7.68	9.38	7.22	9.54	10.82	12.48	8.54	6.30	9.23	9.04
Na ₂ O	5.24	3.79	3.62	2.88	4.55	4.28	4.25	3.15	4.35	2.81
K ₂ O	5.31	4.56	5.62	5.61	5.58	5.13	3.82	6.91	5.04	4.74
H ₂ O	1.72	1.90	1.60				2.08	1.98	2.18	1.68
P ₂ O ₅	0.99	0.59	0.59				0.56	0.79	0.39	0.54
Total	100.26	100.30	99.92				100.14	99.76	100.46	99.58
CaO / MgO	1.69	1.22	1.72				1.04	1.26	1.08	0.93
Na ₂ O + K ₂ O / Al ₂ O ₃ (mol. prop.)	0.83	0.93	0.89				0.63	0.86	1.00	0.78
TiO ₂ × 100	36.08	19.65	21.18				17.67	23.67	28.02	19.70
FeO + Fe ₂ O ₃										
Solidification Index	19.38	28.15	16.48				33.40	18.86	31.51	33.40
Mafic Index	64.78	59.47	74.14				74.14	51.68	50.21	54.97

(Contd.)

Table 2 (Contd.)

CIPW Norms							
Or	26.00	22.72	33.36	22.54	34.27	11.08	20.29
Ab	—	—	6.55	—	—	—	—
An	7.78	2.36	4.17	17.51	5.75	—	7.50
Lc	4.03	3.33	—	—	5.17	14.41	5.89
Ne	23.86	17.32	13.03	19.31	14.43	19.88	12.78
Di	20.08	32.77	23.37	17.27	16.90	34.98	26.53
Ol	7.82	8.25	6.41	16.66	7.55	9.06	12.01
Mt	0.70	6.03	6.26	1.86	6.66	3.01	7.89
Il	5.63	4.25	4.86	2.75	5.17	4.86	4.41
Ap	2.35	1.34	1.34	1.34	1.85	0.92	1.34
Rb	105	120	88	81	220	140	100
Ba	1480	1870	1590	1547	2490	2260	2990
Sr	810	1070	2510	827	1850	1250	890
K/Rb	420.00	315.45	530.15	391.49	260.74	298.85	393.46
K/Ba	29.78	20.24	29.34	20.50	23.04	18.51	13.15
Ca/Sr	103.21	62.65	20.56	93.71	24.34	52.78	72.59
Ba/Sr	1.83	1.75	0.63	1.87	1.35	1.81	3.56
Rb/Sr	0.13	0.11	0.04	0.10	0.12	0.11	0.11

Figure 2. $(\text{Na}_2\text{O}+\text{K}_2\text{O})\text{-CaO-MgO-(FeO+Fe}_2\text{O}_3)$ diagram (wt%) for alkaline basic members of the investigated complex. 1-3. Alkaline gabbro. 4-7. Biotite lamprophyre.

Figure 3. Plots of $\text{TiO}_2 \times 100 / (\text{FeO} + \text{Fe}_2\text{O}_3)$ (wt%) as a function of TiO_2 (wt%) of the alkaline basic members of Elchuru. Explanation same as in Figure 2.

Table 3. *t*-statistic and test of significance between alkaline basic members of Elchuru, Andhra Pradesh, India.

Parameters	$\bar{X}_1$	σ_1	$\bar{X}_2$	σ_2	d_f	t^*	Significance
Alkali feldspar	27.748	9.202	17.88	11.548	8	1.340	H ₀
Clinopyroxene	15.563	10.329	30.225	10.511	8	1.953	H ₀
Biotite	29.87	16.206	47.943	4.163	8	1.952	H ₀
Colour index	66.447	10.303	79.538	10.221	8	1.766	H ₀
SiO ₂	46.48	9.444	45.228	5.558	5	1.851	H ₀
Al ₂ O ₃	14.193	2.093	14.21	2.178	5	0.0086	H ₀
P ₂ O ₅	7.233	1.886	0.57	0.143	5	1.034	H ₀
MgO	5.483	1.574	7.86	1.743	5	1.572	H ₀
CaO	9.52	1.786	8.228	1.169	8	1.097	H ₀
Na ₂ O	4.05	0.746	3.64	0.672	8	0.811	H ₀
K ₂ O	5.302	0.377	5.128	1.123	8	0.314	H ₀
Na ₂ O + K ₂ O	0.883	0.041	0.818	0.134	8	0.695	H ₀
Al ₂ O ₃							
CaO/MgO	1.543	0.229	1.078	0.119	5	2.950	H ₀
TiO ₂ × 100	25.637	7.411	22.265	3.962	5	0.645	H ₀
FeO + Fe ₂ O ₃							
Solidification Index	21.337	4.961	29.318	6.089	5	1.568	H ₀
Mafic Index	66.13	6.065	57.75	9.618	5	1.119	H ₀
Rb	116.333	25.642	135.25	53.364	8	0.669	H ₀
Ba	2416.833	1133.97	2321.75	519.354	8	0.140	H ₀
Sr	1257.833	568.95	1204.25	406.25	8	0.146	H ₀
K/Rb	395.648	86.55	336.13	57.93	8	1.079	H ₀
K/Ba	21.103	6.90	18.8	3.636	8	0.548	H ₀
Ca/Sr	71.093	26.09	60.85	25.572	8	0.548	H ₀
Ba/Sr	2.252	1.324	2.148	0.840	8	0.125	H ₀
Rb/Sr	0.108	0.041	0.11	0.007	8	0.073	H ₀

* *t* - values at 1% level of significance where *t* 3.365, 2.896 (one sided test) and 4.032, 3.355 (two sided test) at respective degrees of freedom (*df*) = 5 and 8.

H₀ = Null hypothesis at 1% level "that the samples are coming from the same population in 99 cases out of 100 trials" are accepted.

dence level (table 3) and hence, all the geochemical characters suggest a close coherence between the two basic members of Elchuru alkaline complex.

4. Conclusion

In summary, the two basic members of Elchuru are very similar in chemistry and mineralogy and it is suggested that the biotite lamprophyres were formed from a basic magma which appeared late in evolutionary sequence of the complex as a result of appreciable hydrous environment by earlier solidification of magmas, metamorphism or rifting (Bailey 1964). Abundance of modal biotite (always > 40%) and phenocrysts

of pyroxene (owing to enhanced growth) in biotite lamprophyre are interpreted as resulting from differences in volatile concentration of the two basic phases.

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