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Trace element geochemistry of parts of the Closepet granite, Mysore State, India[1]

V. DIVAKARA RAO[2]
National Geophysical Research Institute, Hyderabad-7, A.P., India

U. ASWATHANARAYANA
Centre of Advanced Study in Geology, University of Saugar, Sagar, M.P., India

M. N. QURESHY
National Geophysical Research Institute, Hyderabad-7, A.P., India

SUMMARY. Trace elements in twenty samples of the Closepet granite (grey and pink varieties) and the related rocks have been determined by neutron activation analysis (Th, Rb, and Cs), fluorometry (U), flame-photometry (K), and emission spectroscopy (Pb, Sr). The trace element contents of the grey and pink varieties are generally similar. An analysis of the magnitudes of the trace element and other ratios (K/Rb, 235; Th/U, 6·4; U/K ($\times 10^4$), 0·7; K/Cs ($\times 10^{-4}$), 3·6; Th/K ($\times 10^4$), 5·3; $Fe_2O_3/(FeO+Fe_2O_3)$, 0·27) as well as $^{87}Sr/^{86}Sr$ initial ratio (0·705; Crawford, 1969) of the Closepet granite indicate two possible modes of genesis: Either the granite magma was not highly differentiated and the vapour phase was relatively insignificant; the crystallization of the magma took place under essentially non-oxidizing conditions; the pink variety, which followed the grey variety, crystallized under essentially the same conditions as the grey variety. Or the Closepet granite had a two-stage history—palingenesis (starting from the Peninsular gneiss) and metasomatism involving the enrichment in K, Rb, Pb, and Th and depletion of Sr and Cs, among others.

As a part of the investigation aimed at deciphering the mode of origin of the 2380 ± 35 Myr old (Crawford, 1969) Closepet granite, detailed geological, geochemical, and geophysical studies have been made of the northern part of the granite comprising an area of about 750 km^2 (fig. 1). Divakara Rao *et al.* (1972) described the geologic setting, structure, petrology–mineralogy, modal analysis (26 samples), and gravity studies in respect of the Closepet granite and the associated Chitaldrug and Hosdurga granites and Peninsular gneisses. On the analogy of some African granites (Shackleton, 1970), the Closepet granite may have been generated by the reactivation of the basement. The trend of foliation of the granite is generally N–S, which happens to be the direction of fold axis of the Dharwar anticlinorium. The joints in the Closepet granite may have been impressed upon the rock during the post-emplacement history.

There are two varieties of the Closepet granite—the grey and pink varieties, with grey and pink feldspar porphyroblasts, respectively. The boundary between the grey and pink varieties is gradational. The Closepet granite consists of quartz, microcline, plagioclase (albite to oligoclase), biotite, and hornblende. Plagioclase often alters to sericite. Myrmekite is found in a few sections. The presence of unzoned anhedral

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plagioclase, the replacement of plagioclase by microcline, and the presence of perthite and myrmekite (intergrowths of quartz and plagioclase around the boundaries of plagioclase, K-feldspar, and quartz) may be cited as evidences in support of the metasomatism that the Closepet granite has apparently undergone. The average mode (in %) of the grey variety of the Closepet granite is: K-feldspar (inclusive of microcline, myrmekite, and perthite) 49·1, quartz 35·2, plagioclase 10·6, mafics 3·13, accessories 1·84; with Kf/(Kf+Pf) 0·82, Kf/Qz 1·51, mafics/Qz 0·10. The potash-feldspar/total-feldspar, potash-feldspar/Qz, and mafics/Qz ratios are roughly comparable in the grey and pink varieties of the Closepet granite and also in the Chitaldrug granite, but are sharply different from those in the Hosdurga granite.

The major element geochemistry in regard to the above rocks has been reported elsewhere (Divakara Rao *et al.*, 1969).

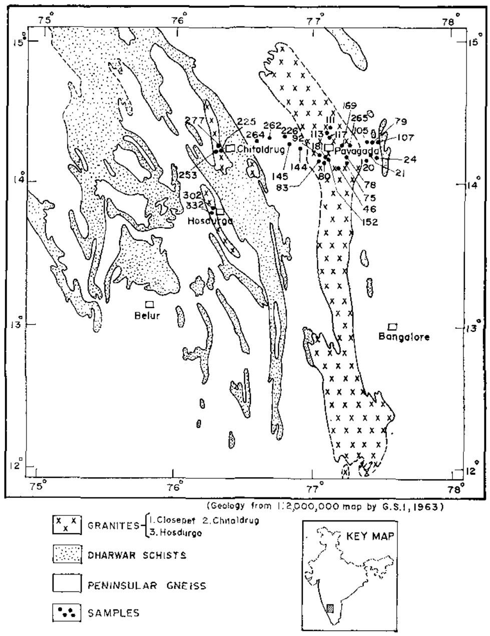

FIG. 1. Geological map of Central Mysore, showing the locations of the Closepet, Chitaldrug and Hosdurga granites.

Analytical techniques. Neutron activation analysis was employed for the determination of thorium (Gangadharam and Parekh, 1968), rubidium and caesium (Gangadharam and Reddy, 1969). Uranium was determined with a Jarrel-Ash G.M. Reflectance type fluorometer, mark V, by the method of Grimaldi *et al.* (1952). Pb and Sr were estimated semi-quantitatively (without internal standard) with a Hilger large quartz Littrow spectrograph. Potassium was determined with B. Lange's flame-photometer, model 6a. The analytical data obtained in the present study for G–2 granite and GSP–1 granodiorite are found to agree within a few per cent with the values accepted by Flanagan (1969).

The data are presented in Tables I to III and plotted in figs. 2 and 3.

Discussion. The grey and pink varieties of the Closepet granite and the white and red varieties of the Heemskirk granite have some common features. In both the cases, the grey (white) variety generally precedes the pink (red) variety. The grey variety usually contains xenoliths, whereas in the red variety the xenoliths are either uncommon or absent. The major element composition of the grey and pink varieties is generally similar in the case of both the granites (Divakara Rao *et al.*, 1969; Heier and Brooks, 1966). There is, however, a sharp contrast between the white and red varieties of the Heemskirk granite in respect of the K/Rb, Th/U, U/K, Th/K,

$Fe_2O_3/(FeO+Fe_2O_3)$, and $^{87}Sr/^{86}Sr$ initial ratios (Heier and Brooks, 1966). As against this, there is hardly any contrast between the grey and pink varieties of the Closepet granite either in trace element abundances (Table I) or in various ratios (Table II). This requires explanation.

TABLE I. *Trace elements (in ppm) in Closepet granite and related rocks*

Sample no.	U	Th	K	Rb	Cs	Pb	Sr
Closepet granite (grey variety):							
75	5·3	34·0	4·2×10⁴	174	1·3	—	—
78	2·9	52·5	4·3	183	1·2	—	—
105	2·0	20·4	3·6	129	1·6	—	—
21	3·5	17·0	4·7	211	1·9	50	180
91	3·8	17·2	4·5	182	1·2	50	145
161	2·8	9·8	2·5	204	3·6	50	80
265	3·5	12·0	3·9	143	0·4	—	—
152	1·4	9·2	3·6	143	1·8	40	110
Average	3·1	19·8	3·9×10⁴	171	1·6	48	130
Closepet granite (pink variety):							
79	2·7	28·3	4·5×10⁴	161	1·0	40	110
111	3·3	19·6	4·3	231	3·1	45	115
80	2·8	13·3	3·1	154	1·5	45	125
82	2·9	6·9	4·5	149	0·5	—	—
107	1·4	3·9	2·7	84	0·7	—	—
20	3·8	8·6	3·8	198	1·5	—	—
83	3·5	18·6	4·2	150	0·8	—	—
117	3·3	35·4	2·8	189	0·8	—	—
Average	2·9	16·8	3·7×10⁴	164	1·2	43	117
Average of Closepet granites as a whole:							
	3·5	18·2	3·8×10⁴	180	1·43	46	124
Chitaldrug granite:							
277	0·9	5·4	4·0×10⁴	60	0·5	40	170
253	1·3	6·6	3·6	—	—	—	
Hosdurga granite and Peninsular gneiss:							
332	7·6	24·8	0·6×10⁴	196	4·7		
226	1·4	2·6	0·5	119	3·9		

Two hypotheses could be proposed to explain the observations in respect of the Closepet granite:

The magnitudes of the Th/U (6·4), K/Rb (235), and $(U/K)\times 10^4$ (0·7) ratios indicate that the granite magma was not highly differentiated and that the vapour phase was generally insignificant. The crystallization of the magma took place under essentially non-oxidizing conditions (as suggested by the low value of the $Fe_2O_3/(FeO+Fe_2O_3)$ ratio). The grey granite, which crystallized earlier, reacted with (and partly homogenized) the pre-existing Peninsular gneiss (in the form of lit-par-lit injections or in a cupola environment?). This is evident from the existence of both sharp as well

TABLE II. *Averages of ratios of trace elements in the Closepet granite and related rocks*

Ratio	Closepet granite (grey)	Closepet granite (pink)	Closepet granite (both varieties)	Chitaldrug granite	Hosdurga granite	Peninsular gneiss
K/Rb	236	234	235	576	31	42
Th/U	7·2	5·5	6·4	6·2	3·3	1·9
$(U/K)\times 10^4$	0·67	0·79	0·73	0·28	12·19	2·73
$(Th/K)\times 10^4$	5·3	4·6	5·0	—	—	—
$(K/Cs)\times 10^{-4}$	3·08	4·08	3·58	3·66	0·13	0·13
Rb/Sr	2·10	1·21	1·55	0·35	—	—
Pb/U	18·5	14·7	16·9	—	—	—
$Fe_2O_3/(FeO+Fe_2O_3)$	0·29	0·26	0·27	0·37	0·45	0·41

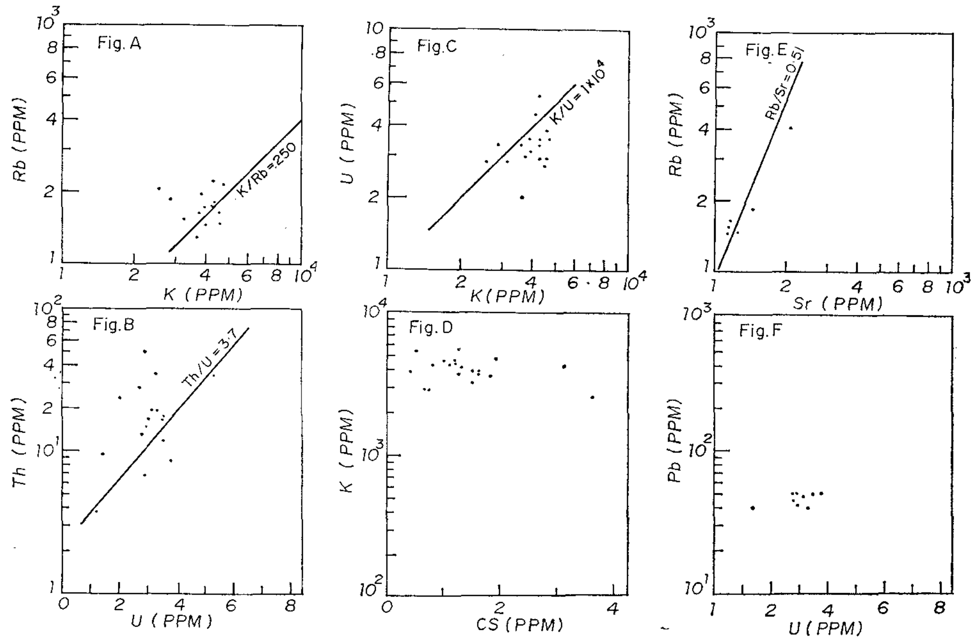

FIG. 2. Scatter plots for various trace elements in the Closepet granite.

as gradational contacts between the Peninsular gneiss and the Closepet granite (grey), but due to the virtual absence of vapour phase, a granite characterized by low K/Rb, low Th/U, and high U/K ratios (similar to the white variety of the Heemskirk granite) did not come into existence. The pink variety of the Closepet granite, which followed the grey variety, crystallized under essentially the same conditions as the grey variety. The pink variety interacted both with the grey variety and the Peninsular gneiss.

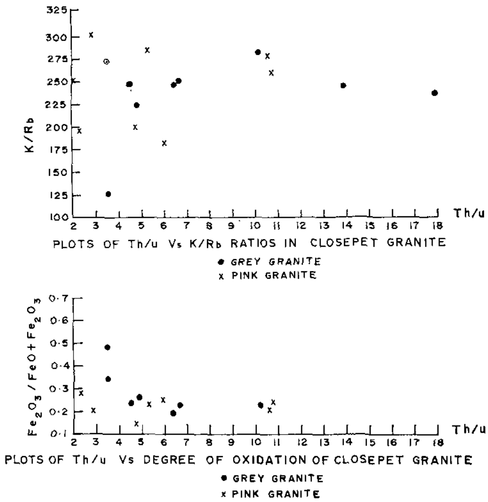

FIG. 3. Th/U *vs.* K/Rb and Th/U *vs.* $Fe_2O_3/(FeO+Fe_2O_3)$ scatter plots for the Closepet granite.

The $^{87}Sr/^{86}Sr$ initial of $0{\cdot}705 \pm 0{\cdot}0014$ (Crawford, 1969) of the Closepet granite as a whole is consistent with the above hypothesis as per the model of Hurley *et al.* (1962). Significantly, the 790 ± 60 Myr old (Crawford, 1969) pink granite of Chamundi Hill in Mysore State has the same initial ratio of $0{\cdot}7050 \pm 0{\cdot}0013$ as the Closepet granite, and both are similar to the minimum value (0·705) for the red Heemskirk granite, which value is fairly common for high-level granites (K. S. Heier, personal communication). It should, however, be pointed out that the Heemskirk granite is atypical (K. S. Heier, personal communication) and the absence of concordance in the postulated modes of genesis of the Heemskirk and Closepet granites is to be expected.

Alternatively, the Closepet granite might have had a two-stage history: palingenesis, starting from the Peninsular gneiss of Mysore (2585 ± 40 Myr old), and metasomatism involving enrichment in Th, Rb, K, and Pb and depletion in Sr and Cs, among others. Some of the evidences in favour of this second hypothesis are discussed below:

Th/U ratio: Granites in the upper parts of the continental crust usually have 3 to 4 ppm of U and 10 to 15 ppm of Th (Adams *et al.*, 1959) with a Th/U ratio of 3·7 (Wasserburg *et al.*, 1964). The average uranium contents of the pink (3·0 ppm) and grey Closepet granites (3·2 ppm) are roughly comparable. The thorium content of the grey granite (19·8 ppm) is, however, somewhat higher than that of pink granite (16·8 ppm) resulting in Th/U ratios of 7·2 and 5·5 respectively for the grey and pink varieties. These insignificant differences may be attributed to the degree of presence of xenoliths in the two varieties.

Rogers and Adams (1969) listed several provinces characterized by high Th concentrations (>20 ppm) or high Th/U ratios (>4) or both. The Conway granite has a markedly high Th content (56 ppm) but a normal Th/U ratio of 3·7 (Rogers *et al.*, 1965). On the other hand, the Enchanted Rock batholith granite of Texas has slightly more than normal Th content (20 ppm) but a markedly high Th/U ratio of 6 (Rogers, 1964). The Closepet granite is similar to the latter granite, both in respect of Th content (19·8 ppm) and Th/U ratio (6·4). Whitfield *et al.* (1959) have shown that the Precambrian granites are usually characterized by high Th/U ratios, possibly because of comparatively low uranium content. The distribution of U and Th in the batholith and hence the Th/U ratio is partly controlled by secondary processes (Ragland *et al.*, 1967).

The high Th/U ratio of the Closepet granite can be explained in two ways: Th might have been introduced during the process of metasomatism; the studies of

Kolbe and Taylor (1966) broadly indicate that gneissic granites of metasomatic origin tend to have higher Th/U ratios (4·5 to 5) than bonafide magmatic granites (2·2 to 3·3). Or the Closepet granite may be a thorium province; the anomalously high ^{208}Pb content relative to ^{206}Pb in the pegmatitic feldspar leads (Aswathanarayana, 1959), the preponderance of Th reserves relative to U reserves in India (Bhabha and Prasad, 1959), and the high Th content of kimberlites (with granitic xenoliths) of Andhra Pradesh (Gangadharam and Aswathanarayana, 1969) are generally consistent with the possibility that parts of the crust of Peninsular India may be characterized by a high Th/U ratio. This feature may be reflected in the Closepet granite as well.

K/Rb ratio: The concentration of K and Rb and the magnitude of K/Rb ratios of the pink and grey varieties of the Closepet granite are generally similar. The slightly high Rb content of the grey granite relative to that of the pink variety may be due to the higher percentage of K-feldspar in the former. The average K/Rb ratio (235) of the Closepet granite as found here is more akin to that of metasomatic granite (K/Rb 205) than to that of magmatic granites (K/Rb 100 to 160, Kolbe and Taylor, 1966). The K/Rb ratio cannot, however, differentiate between magmatic and metasomatic granites unequivocally.

The *U/K ratio* of the Closepet granite ($0{\cdot}7 \times 10^{-4}$) is slightly less than that expected in the crustal rocks including granites ($1{\cdot}0 \times 10^{-4}$).

K/Cs ratio: The Cs concentration of the grey variety of the Closepet granite (1·6 ppm) is high compared to that of the pink variety (1·2 ppm). As the K content of both the varieties are similar, this leads to a lower K/Cs ratio for the grey variety ($3{\cdot}1 \times 10^{4}$) than that of the pink variety ($4{\cdot}1 \times 10^{4}$).

The high K/Cs ratio ($3{\cdot}6 \times 10^{4}$) of the Closepet granite as a whole is due to the inherently low Cs content of the granite (1·4 ppm). The Cs values reported by Heier and Adams (1959) for granites elsewhere range from 5 to 11 ppm. The studies of Kolbe and Taylor (1966) indicate that granites of metasomatic origin tend to have lower Cs content and higher K/Cs ratio than the granites of magmatic origin. This observation is consistent with a metasomatic origin for the Closepet granite.

Rb/Sr ratio: Seven Sr determinations were made in the present investigation and they are relatively less reliable because they were determined by emission spectroscopy methods. The Rb/Sr ratio in a granite could vary widely from 0·53 to 26·68 (Fairbairn *et al.*, 1967). Ahrens (1965) gives an average of 150 ppm of Rb and 290 ppm of Sr (Rb/Sr 0·51) for granites. In the case of the Closepet granite, the corresponding figures are Rb 180 ppm, Sr 124 ppm (Rb/Sr 1·55). This could mean that the Closepet granite might have been enriched in Rb and depleted in Sr at the time of metasomatism.

Pb/U ratio: The average Pb concentration (46 ppm) and Pb/U ratio (16·9) of the Closepet granite are much higher than the corresponding values (9·3 ppm; 3·4) for the granite of Ontario, Canada (Tilton *et al.*, 1955). Usually, most of the uranium is concentrated in the accessory minerals like zircon and sphene, while the bulk of non-radiogenic lead resides in feldspars and quartz. Consequently, feldspathization of a rock during metasomatism tends to enhance the Pb content (Pb^{2+} substitutes for K^{+} in feldspars), and thus results in a high Pb/U ratio. This process might have operated in the case of the Closepet granite.

Radioactive heat production and radiation dosage levels: The average rates of radioactive heat production using the values of Birch (1954), and the approximate radiation dosage levels using the values cited by Adams and Lowder (1964), for the various granites, are given in Table III. Wollenberg and Smith (1968) have found a positive correlation between the rate of radioactive heat production and silica content in the rocks of Sierra Nevada batholith, California. No such correlation is found in the case of the Closepet granite.

TABLE III

Rock type	Radioactive heat production		Radiation dosage
Closepet granite (grey variety)	$7{\cdot}65 \times 10^{-6}$ cal g^{-1} yr^{-1}	$5{\cdot}82 \times 10^{-13}$ cal cm^{-3} sec^{-1}	16·89 μr hr^{-1}
Closepet granite (pink variety)	6·78	5·55	15·20
Closepet granite (both varieties)	7·21	5·68	16·05
Chitaldrug granite	3·04	2·58	9·61
Hosdurga granite	10·67	9·07	15·74
Peninsular gneiss	1·65	1·42	2·83

Conclusions

The Closepet granite (both grey and pink varieties) might have been generated from a granite magma (which was not highly differentiated and in which the vapour phase was insignificant) under essentially non-oxidizing conditions. Alternately, it might have had a two-stage origin: palingenesis, starting from the Peninsular gneiss, and metasomatism involving enrichment in Th, Rb, K, and Pb and depletion in Sr and Cs, among others. The petrological and major element evidence are not inconsistent with the second model (Divakara Rao *et al.*, 1969, 1972).

According to Heier–Brooks model (1966), the Hosdurga granite will have to be considered as a highly differentiated granite (with large vapour phase), which crystallized under oxidizing conditions. It is equally possible that it might have been generated by the palingenesis and metasomatism of the Peninsular gneiss, but at a level less intense than is manifest in the Closepet granite. The field evidence generally favours the latter possibility. The Chitaldrug granite is akin to the Closepet granite in respect of Th/U, Th/K, and $Fe_2O_3/(FeO+Fe_2O_3)$ ratios but not in regard to K/Rb ratio. As only a few samples of Hosdurga and Chitaldrug granites have been analysed, it is hazardous to draw any far-reaching conclusions.

The granites of the Singhbhum region, Bihar, Eastern India, which are the only other granites for which comparable trace element data are available (Saha *et al.*, 1970), are sharply different from the Closepet granite and are more akin to the grey Heemskirk granite.

As, in India, the economically important hydrothermal uranium mineralization is confined to areas where the granites are characterized by low Th/U and high U/K ratios (such as in Singhbhum), the problem acquires considerable economic significance (Aswathanarayana, 1971).

As the grey and pink varieties are common in the granitic terrains in India and elsewhere in the world, the problem of their genesis is of universal interest. We have described a mode of origin of the grey and pink varieties different from that of Heier and Brooks (1966). It is possible that there may be still other modes of genesis. Trace elements and Sr, Pb, and O isotopes constitute powerful tools to investigate the problem further.

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