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Radioactive element distribution in the Archean granulite terrane of Jequié – Bahia, Brazil

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Abstract. The radioactive element distribution in the Archean granulite facies rocks of Jequié, Brazil, has been determined. The K/Rb ratios show a large spread with majority of the values falling within the normal field (K/Rb < 300). The Th/U ratios fall into two groups, one group with values in the range of 1.7 to 2.6, whereas the other group show Th/U values greater than 7 (7 to 25). These distributions can be explained on the basis of the presence of accessory minerals apatite and zircon. The relatively high concentrations of the radioactive and other elements in Jequié granulites probably represents the relict primary geochemical character, little modified during metamorphism. The radiogenic heat production data for the area are calculated and using the measured regional heat flow value from nearby area an estimate of the relative thickness of the continental lithosphere is made using the model developed by Oxburgh (1981).

Introduction

Nearly all known regions of the old continental crust have surface exposures of high grade regionally metamorphosed rocks where granulites occur in large volume. Though recent years have witnessed a vast accumulation of data on the geochemical nature of the granulites (Lambert and Heier 1968; Sighinolfi 1971; Tarney et al. 1972; Sheraton et al. 1973; Drury 1973; Wilson 1978; Barbey and Cuney 1982), relatively few studies on the distribution of U, Th and K and the regional heat production in these areas have been undertaken (Oxburgh 1981). Summarising the geochemical trend observed for the granulites, Tarney (1976) observed that "there is a duality in their lithophile element abundances i.e., K, Rb, Cs, Th and U are moderately to highly depleted, while Ba, Sr, Zr, Ce and La are normal or even enriched compared with amphibolite facies gneisses". Rollinson and Windley (1980) observed that "depletion" is a selective process. Barbey and Cuney (1982) discussed the factors that control the large ion lithophile element fractionation in Lapland granulites and suggested that the fractionation (depletion) process is controlled by original lithology and mineralogy, mineral – fluid equilibria during progressive (retrogressive) metamorphism and mineral-melt-fluid equilibria during anatexis. Further, statistical analysis on K-Rb distribution in the various rock types by these authors showed that there is no metamorphic trend characteristic of granulite facies terranes as suggested. Gray (1977) observed, from his study on the granulites of Tomkinson Ranges, Central Australia, that depletion of uranium is a process accompanying granulite facies metamorphism. Allen (1979) concurs with such a view, while discussing the geochemistry of granulites of Strangways Range, Central Australia, and suggests that Th/U ratio should be used as a suitable indicator of elemental depletion.

Sighinolfi et al. (1981a) carried out a geochemical and petrographic study on the Archean granulite terrane of Jequié, Brazil. They observed that the rocks are granitic in composition, with normal concentrations of U and Cs, and slight enrichment of elements like Rb, Y, Zr, Na, Ba and R.E. The geochemical nature of the rocks was interpreted by these authors as due to a later metasomatic event, which added trace elements in sufficient quantities to rocks earlier depleted in trace elements. Such a mechanism of metasomatic event enhancing trace element contents was invoked by Allen (1979) to explain the trace element abundance of granulite facies rocks in the Arunta block, Central Australia.

Two of the present authors have carried out a detailed geochronological investigation in the granulitic terrane of Bahia using Rb-Sr and K-Ar dating techniques (Cordani and Iyer 1979). Some of the samples used for the Rb-Sr dating programme were selected and accurate analysis of U, Th, K and Rb were carried out on them. The samples selected are from the same area where Sighinolfi et al. (1981a) have carried out their geochemical study. The results obtained are discussed in the light of the petrological, geochemical and geochronological data and an evaluation of the hypothesis of Sighinolfi et al. (1981a) is made based on our data. The radiogenic heat production value for the area is calculated and its implication for the continental crustal thickness is discussed.

General geology

The general geology of the area has been discussed by Cordani (1973), Pedreira (1976), Moutinho da Costa and Mascarenhas (1982). The granulite facies rocks that constitute the high grade metamorphic complex of Jequié consist of fine to medium-grained banded granulites exhibiting gneissic structure. Geochronological studies, mainly Rb-Sr and K-Ar, demonstrate the presence of a 2,700 m.y. event, related to the granulite facies metamorphism and referred to as Jequié. Near Mutuipe area (see Fig. 2 – Cordani and

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Iyer 1979) Rb-Sr data points have yielded isochrons in the range of 3,100–3,500 m.y. (Cordani and Iyer 1979; Moutinho da Costa and Mascarenhas 1982), the geological significance of which is not yet clear. Other radiometric dating methods like U-Pb, Pb-Pb and Sm-Nd applied to this area should shed further light on the geological evolution of this terrane. The rock samples analysed are from near Mutuipe region (see Fig. 2 – Cordani and Iyer 1979 for sample locations).

Petrography

Petrographically these rocks comprise mainly felsic granulites, with a few intermediate to mafic types varying in composition from charnockitic to enderbitic. With decreasing alkali feldspar and quartz from the former to the latter, there is a clear variation from medium to fine-grained rocks with a concomitant increase in gneissic character marked by the orientation of the mafic minerals. There is no regular distribution of felsic and mafic rocks around Mutuipe. In thin section, textures are seen to vary from somewhat equigranular interlobate in the charnockites to inequigranular polygonal in the enderbites.

A characteristic feature of the charnockites is the predominance of mesoperthite with lesser amounts of quartz, plagioclase and myrmekite. Some of these show interlobate and embayed margins, as well as irregular drop – like quartz that might be taken to indicate incipient melt formation according to the interpretation of similar textures by Mehnert et al. (1973). Such textures are lacking in the mafic granulites. Furthermore, the mesoperthites at places grade into microcline which is then developed interstitially; a sign of slight retrogression and/or a result of incipient potash metasomatism consequent on formation of granitic melts in these rocks, which is possible under typical granulite facies conditions (see Bohlen et al. 1982).

Common mafic minerals occurring sporadically are orthopyroxene relicts, brown hornblende, minor red brown biotite and green chlorite as an alteration product; accessory minerals are zircon and apatite, both occurring as large euhedral grains, and some opaques.

The mafic granulites consist of plagioclase, sometimes antiperthitic, pleochroic pink orthopyroxene, clinopyroxene, brown hornblende and quartz; the mafic minerals sometimes occur as aggregates in certain portions of the rocks, but on the whole well oriented. Occasionally both pyroxenes show (100) exsolution lamelle attesting to their slow cooling from high temperatures. These rocks also contain apatite and zircon as common accessory minerals.

Analytical techniques

Generally, studies on the distribution of the radioactive elements U, Th and K in granulite facies terranes (Lambert and Heier 1968; Sighinolfi and Sakai 1977; Gray 1977) are carried out by sealed can γ ray spectrometry, where high analytical errors are associated with the measurements of uranium at low concentrations. Heier and Thorensen (1971) and Gray (1977) reported precision of 10% for U values. Sighinolfi et al. (1981 a) reported U and Th measurements for the granulite facies rocks of Jequié by X-ray fluorescence technique. From their results it can be inferred that the limit of detection for U and Th is above 1 ppm.

Hart et al. (1980) observed that X-ray fluorescence technique provides data with precision comparable to mass spectrometric isotope dilution technique (MSISD) and instrumental neutron activation analysis (INAA) at concentrations of U and Th above 10 ppm. The INAA technique yielded U and Th data comparable to those obtained by MSISD over the entire range of concentration studied (U 0.4–56 ppm; Th 5–63 ppm).

In the present investigation an INAA technique similar to that described by Hart et al. (1980) was employed. About 100 mg of sample was wrapped in aluminium foil and placed in a cylindrical aluminium can lined with 1 mm of cadmium shield. To avoid errors due to the fluctuations in the flux gradient in the can, the samples and standard (one standard for two samples) were placed close to each other and irradiated in a position where the thermal neutron flux is of the order of 5×10^{12} n·cm^{-2} sec^{-1} for about 64 h in the research reactor IEA-RI of the Instituto de Pesquisas Energéticas e Nucleares, São Paulo.

The activated samples were counted for about 3,000 seconds, after a cooling period of about 65 to 150 h, in an Ortec Win-15 Ge (Li) detector having a resolution of 2.45 KeV for the 1,332.5 KeV peak of ^{60}Co at a warranted efficiency of 15%. The spectra were accumulated with an Ortec 4096 channels analyzer and data reduction was achieved by the ORTEC GELIGAM V3D (ORACL) programme (Gamma 2, V12). Uranium was determined using the characteristic gamma ray spectrum accompanying the decay of ^{239}Np (t1/2 = 56.64 h) and the peak at 278 KeV. Thorium was determined using the decay of ^{233}Pa (t1/2 = 27.4 days) and the peak at 312 KeV. The USGS rock BCR-1 was used as standard for the determination of U and Th.

Along with the granulite samples, U and Th contents of two granite samples (DDH-7; GM (1) 230.95) from Wyoming were determined by INAA. These samples have already been analysed for their U and Th contents by various analytical techniques, like MSISD (Stuckless et al. 1977; Kakazu et al. 1981), alpha spectrometric isotope dilution technique, and delayed neutron method (Stuckless et al. 1977). Table 1 shows that the values obtained in the present study are in good agreement with other methods, specially MSISD.

Replicate analyses of the samples showed that the precision of the analysis for U and Th is of the order of 2 to 3%. Potassium and rubidium concentration in the rocks were determined by usual X-ray fluorescence method with a precision of ±1%.

Table 1. Comparison of the U, Th values in granitic samples of Wyoming, obtained by different analytical techniques

Sample	Uranium				Thorium			
	Isotope dilution		Delayed neutron (1)	INA A (3)	Isotope dilution (1)		Delayed neutron (1)	INA A (3)
	Mass spec	Alpha spec (1)			Mass spec	Alpha spec		
DDH 7	3.69 (1) 3.62 (2)	3.60 –		3.7	46.03 –	40.0	– –	46.4 –
GM (1) 230.95	11.13 (1) 11.30 (2)	11.18 –	10.9 –	10.9 –	6.77 –	6.69 –	6.08 –	6.50 –

(1) Stuckless et al. (1977; (2) Kakazu et al. (1981); (3) Present work

Results and discussion

The U, Th, K and Rb values measured are listed in Table 2. K/Rb ratios of the rock samples show a large variation with nearly half of the values falling within the conventional normal field (K/Rb < 300).

The trace element data of Sighinolfi et al. (1981a) also show the same trend, thereby demonstrating that there is no fractionation of Rb with respect to K. Rollinson and Windley (1980) and Barbey and Cuney (1982) have found that fractionation of Rb is not observed in all rock types belonging to granulite facies. These authors consider that fractionation is controlled by various factors like original lithology, mineral fluid equilibria during metamorphism, amount of fluid participating etc.

Table 2. U, Th, K and Rb values for granulites of Jequié

Sample	Rock type	U ppm	Th ppm	K (%)	Rb ppm	Th/U	K/Rb
MU 19 A	Felsic granulite	5.9	14.5	4.55	263	2.5	173
MU 46	Felsic granulite	0.92	2.4	3.70	83	2.6	445
AM 9	Mafic granulite	0.62	4.5	3.40	82	7.3	414
MU 19 B	Felsic granulite	23.9	51.2	3.81	187	2.1	203
MU 44	Mafic granulite	1.9	33.3	2.96	73	17.5	405
SAJ-36	Mafic granulite	2.2	54.0	4.04	109	24.8	371
SAJ-28	Felsic granulite	3.5	35.0	4.44	166	10.0	267
GD 97	Felsic granulite	0.74	1.9	4.08	115	2.6	354
Milagres	Felsic granulite	2.9	35.9	5.04	156	12.4	323
VQ 243	Felsic granulite	5.5	50.5	4.20	110	9.2	381
BJ-2	Felsic granulite	4.4	52.7	4.63	123	12.0	376
BJ-12	Felsic granulite	2.8	5.0	5.04	320	1.8	158
BJ-10	Felsic granulite	1.3	2.2	5.00	324	1.7	154
BJ-20	Mafic granulite	1.8	16.3	4.08	149	9.1	273

Uranium contents of the rock samples vary from 0.6 ppm to 6 ppm (except MU19B), while the Th abundances are in the range of 1.9 to 54 ppm (Fig. 1). From Fig. 1 it can be seen that the rock samples can be divided into two groups; one group having Th/U values in the range of 1.7 to 2.6 (BJ-10, BJ-12, GD-97, MU-19A, MU-19B, MU46) and a second group having much higher Th/U values, in the range of 7 to 25 (AM-9, MU-44, SAJ-36, SAJ-28, Milagres, VQ243, BJ2, BJ20). The pattern can be explained as due to a greater spread in thorium values.

Higher thorium contents are due to the presence of the accessory mineral apatite, which concentrates Th. Typical examples are the pairs BJ-12 – Milagres and BJ20 – MU44, where the samples Milagres and MU-44 contain higher amounts of apatite.

The variation in the uranium contents of the rock samples is the result of the relative abundance of zircon and to some extent apatite. Recently Krasnobayev (1982) has tried to relate the types of zircons and their composition with the origin of charnockitic rocks in which they occur. Referring to this work the euhedral zircons from Jequié would fit in the category of charnockites from deep seated fault zones; however due to their high U and Th contents originating no doubt from the substantial contributions of zircon and apatite, the rocks do not appear to conform to this subdivision.

A comparison of the radioactive element distribution in the granulites of Jequié with the rocks belonging to granulite facies from different parts of the world is attempted (Table 3). The average value obtained in the present work is in the same range as observed by Sighinolfi et al. (1981a) for the rock samples of the area. The mean U, Th and K contents shown in Table 3 is the weighted average of the values based on our data and those of Sighinolfi et al. (1981a). The granulites of Jequié have higher radioactive elemental concentration and further their radioelement distribution does not follow the general trend observed for the Archean rocks by Lambert et al. (1976). These authors observed that the Th/U ratios are in the range of 8 to 15 and that $K/U > 10^4$. The granulites of Jequié do not

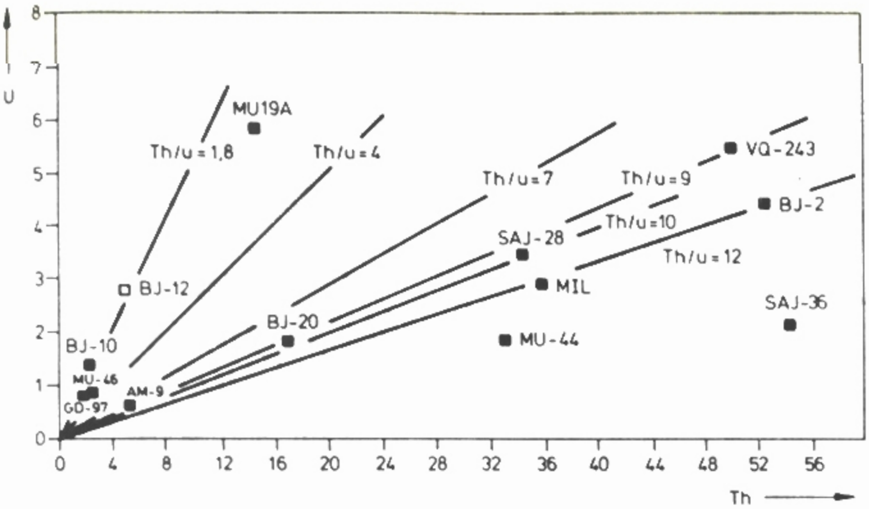

Fig. 1. Uranium-Thorium distribution in the granulite facies rocks of Jequié, Bahia-Brazil

Table 3. Concentration of radioactive elements, radiogenic heat production and heat flow values

Locality and rock type	U ppm	Th ppm	K (%)	Radiogenic heat production μW/m³	Regional heat flow mW/m²	Reference
1. Archean granulites, North Arcot South India $n=17$	0.8	1.1	0.8	0.38	–	Iyer and Kutty (1977)
2. Amitsoq gneisses (Archean)	0.33	0.56	2.2	0.38	–	Lambert et al. (1976)
3. Lewisian granulites (Archean)	0.11	0.65	0.46	0.13	–	Lambert et al. (1976)
4. Proterozoic granulites, Tomkinson Ranges Central Australia $n=43$	0.83	15.5	2.53	1.60	–	Gray (1977)
5. Proterozoic granulites, Musgrave Ranges Central Australia $n=19$	0.48	1.76	0.58	0.32	–	Wilson (1978)
6. Proterozoic granulites, Frazer Ranges Central Australia $n=27$	0.65	1.75	0.92	0.40	–	Wilson (1978)
7. Proterozoic granulites, Strangways Ranges Central Australia $n=26$	0.47	1.27	0.33	0.25	–	Wilson (1978)
8. Early Proterozoic amphibolites, Jacobina-Bahia-Brazil	1.2	13.4	1.73	1.46	49	Vitorello et al. (1981)
9. Archean granulites, Caraiba-Bahia-Brazil	–	–	–	0.78	39	Vitorello et al. (1981)
10. Archean granulites, Itaberaba-Bahia-Brazil $n=19$	0.92	18.5	3.02	1.89	45ᵃ	Sighinolfi and Sakai (1977)
11. Archean granulites, Jequié, Bahia-Brazil $n=28$	2.3	23.0	4.1	2.7	45ᵃ	Sighinolfi et al. (1981a) Present work
12. Early Proterozoic granulites-Pouso Alegre-Minas Gerais-Brazil	1.5	2.0	2.41	0.81	–	Fernandes (1982)
13. Western Australian Shield				3.4	39	Bunker et al. (1975) Jaeger (1970)

Radiogenic heat production: $A\ (\mu W/m^3) = (0.27\ K_2O\% + 0.2\ \text{Th ppm} + 0.73\ \text{U ppm}) \times \frac{\text{density}}{7.55}$, density = 2.67 g/c.c.

ᵃ Estimated regional heat flow

show any correlation between K and U and show high concentrations of incompatible elements and rare earth elements.

To explain the unusual trace element concentration, Sighinolfi et al. (1981a) invoked three plausible mechanisms, namely:

a) Dehydration without partial melting and substantial loss of minor elements.

b) Absence of partial melting due to lack of fluid.

c) Retrograde metamorphism accompanied by reintroduction of mobile elements whereby the rocks were recharged with U-Rb.

The above mentioned authors favor the third hypothesis and discard the possibility of the participation of CO_2 fluids inhibiting melting and causing simple dehydration (Rollinson and Windley 1980). However the introduction of many elements, and specifically Rb during a later metasomatic activity, would have completely disturbed the good alignment of the Rb-Sr isochron data points obtained by Cordani and Iyer (1979). The geochronological studies of Cordani (1973), Cordani and Iyer (1979) for the granulite samples of Jequié yielded Rb-Sr isochron dates of 2,730 ± 50 m.y. Recent geochronological investigation in the region by Moutinho da Costa and Mascarenhas (1982) has yielded significant information to enlarge and increase the representativity of the area dominated by Late Archean ages. Sighinolfi et al. (1981a) invoke an extensive crustal thrusting mechanism, wherein large masses of crystalline metamorphic rocks move over low grade younger rocks. In Bahia, the younger rocks may belong either to the Contendas-Mirante fold belt of lower Proterozoic age or the supracrustals of the Espinhaço Supergroup of middle Proterozoic age. Hence, the introduction of Rb by metasomatism over very large areas of supposedly overlying high grade terrane would have occured during Proterozoic. The consistent Archean age data obtained over a large area by Rb-Sr method totally contradicts the mentioned model.

Lower concentrations of heat producing elements have been observed for the granulite facies rocks from Itaberaba and Salvador regions (Sighinolfi 1971; Sighinolfi and Sakai 1977) in Bahia, where the Rb-Sr isochron dates are lower than those obtained in Jequié-Mutuipe area (Cordani 1973; Cordani and Iyer 1979). Thus, if at all a case is to be made for a later important petrogenetic and geochemical event, the radiometric dates would point to regions of Itaberaba and Salvador as probable candidates rather than Jequié. A mobile belt skirts the region north of Jequié complex, in which anatexis, migmatization and probably associated metasomatic processes occured during lower Proterozoic times (2,000–2,100 m.y. – Brito Neves et al. 1980). In this area the migmatites in general exhibit a granulite paleosome similar in all respects to the Jequié granulites.

The first possibility discussed by Sighinolfi et al. (1981 a), in which the chemistry of the original parent material was not modified during granulite facies metamorphism is preferred by us (see also Sighinolfi et al. 1981 b). The R.E.E. distribution patterns for granulites of Bahia is similar to that of charnockites of Norway, quartz monzonites from Barberton, South Africa and from Minnesota (Sighinolfi et al. 1981 a), and could be explained in terms of feldspar fractionation and crystallisation of apatite, Ca-amphibole, Ca-pyroxene (Petersen 1980). Since Rb, U and Th, like trivalent R.E.E., do not enter early cumulate minerals, their concentration also increases with the increase in differentiation index of the rocks, and these elements are enriched in later magmatic fractions (Ormaasen 1977). Apatite and zircon have higher partition coefficients for R.E.E. than common rock forming minerals and show negative europium anomaly. Further, apatite shows a relative increase in light R.E.E.; whereas in zircon partition coefficients are high for heavy R.E.E., and decrease rapidly for light R.E.E. (Nagasawa 1970). The R.E.E. distribution pattern for Jequié rocks (Fig. 7 – Sighinolfi et al. 1981 a) showing a slight increase in heavy R.E.E. is probably due to the different behaviour of zircon and apatite present in the rocks. Coolen (1980) observed that R.E.E. distribution in granulites is governed by the premetamorphic nature of the rock types with a strong indication of heavy R.E.E. mobility during retrogression.

In this regard it is interesting to note that Wilson (1978) observed a prominent zone in the Frazer Ranges, Western Australia, where granulites show significantly higher values of U, P, Ba, R.E.E., Th, Zr, Rb, Ti, Y, K. This was explained as due to the rocks having higher concentrations of apatite, zircon and K-feldspar, which represent a relict primary composition. Although many authors have interpreted U, Th distribution in high grade metamorphic rocks as signifying loss of U during metamorphism (Lambert and Heier 1967; Sighinolfi and Sakai 1977; Gray 1977), in the case of granulites of Jequié U and Th, concentrated mostly in accessory minerals, are retained even after metamorphism. Thus, the geochemical nature and geochronological data of the granulites of Jequié can be explained on the basis of original parental material being little modified during metamorphism.

The duality of lithophile elemental distribution of granulites is manifested in the fluid inclusions. Granulites with normal lithophile elemental abundances, like those of Tanzania (Coolen 1982), have a very few fluid inclusions; on the other hand other granulites have many generations of inclusions trapped at different times indicating that large amounts of fluid went through the rocks (J. Touret, 1981 and pers. comm.). Large amounts of CO_2 in the CO_2-H_2O mixture that pass through the rocks may incongruently dissolve feldspar and liberate alkalis and other elements (Glassley 1983), causing lithophile elemental fractionation. Some granulites probably do not suffer elemental fractionation, when the relative volume of the fluid flow through them is not large enough (J. Touret, per. comm., Rollinson and Windley 1980).

Sighinolfi et al. (1981 b) published a paper in which the geochemical nature of the Jequié rocks is explained as due to fractionation under low H_2O partial pressure. Accepting such a model, we consider that the Jequié granulites may have originated partly by deep melting of crustal components, with anatexis preceeding granulite facies metamorphism (Janadhan et al. 1982). In that case, the formation of charnockites from previous basement gneisses and simultaneous granulite facies metamorphism can be taken to be coincident with the Jequié event. The abundant mesoperthite in the charnockites and the stability of the anhydrous minerals are evidence for low P_{H_2O} nevertheless it is possible that even in the presence of low X_{H_2O} in the vapour phase, "granitic" phase could still form within the conditions of granulite facies (Bohlen et al. 1982). Such melts could be carriers of high U and Th, so that their values in charnockites reflect original concentration. According to recent view, Archean granulite facies metamorphism may be separated from crust formation by a significant time interval, as was shown by geochronological investigations in Antarctica (De Paolo et al. 1982). The rocks around Mutuipe regions may be similarly related to older crust later subjected to the Jequié event.

,In Table 3 the radiogenic heat production data for the granulite terranes from many parts of the world are shown. They range from 0.1 to 2.3 $\mu W/m^3$, which is in agreement with the observation of Oxburgh (1981) that the variation in heat production for shield areas is more than an order of magnitude. This may be due to the fact that properly controlled statistically valid estimates are not available. According to the above mentioned author, the high grade metamorphic rocks exposed at surface, if ever, become so depleted in heat producing elements that their heat production falls below 0.2 $\mu W/m^3$, even though it is hard to establish an upper bound for the mean crustal heat production. The average crustal radiogenic heat production value for the granulites of Jequié is calculated from the data of Sighinolfi and Sakai (1977) for Itaberaba region and the data for Mutuipe region from the present work and the investigation of Sighinolfi et al. (1981 a). Although the value obtained is higher than that reported from other terranes, where rocks belonging to granulite facies occur, it is of the same order as observed for the Western Australian shield based on the data of 36 Archean granitic rocks (Bunker et al. 1975).

In the old continental crust of Bahia, heat flow values are available from the Late Archean granulite and Lower Proterozoic amphibolite facies gneisses and migmatites of Caraiba Complex and the Lower Proterozoic rocks of Jacobina group (Vitorello et al. 1980; Hamza 1982; Hamza and Eston 1983). There are no heat flow data available for the crustal segment in Itaberaba-Mutuipe region of the Jequié Complex. However, measurements at Jacobina, Caraiba, Arrial and Recôncavo provide an approximate value of 45 mW/m^2 representative of regional heat flow and the average heat production for the region is 2.3 $\mu W/m^3$. Oxburgh (1981) has presented a model to investigate the lithospheric thickness difference between old oceanic crust and old continental crust based on heat flow data, surface radiogenic heat production values and the vertical distribution of continental heat production. If one considers the above mentioned average regional heat flow (45 mW/m^2) and heat production (2.3 $\mu W/m^3$) values as representative of the Mutuipe-Itaberaba region, then the use of Oxburgh's model shows that the lithosphere under this region is 150 km thicker than old oceanic crust.

Greater thickness for lithosphere underlying old continental region has been proposed by various authors (Sclater and Francheteau 1970; Jordan 1975a, b, 1978; Davies 1979) based on different considerations. According to Jordan (1975a, b, 1978), beneath the ancient shields the mass which translates coherently in the course of horizontal motion (tectosphere) is at least 400 km thick. In the model proposed by Davies (1979) the Precambrian shields have been underlain by mechanically and chemically distinct mantle root zones extending to depths of at least 200 km. Such root zones would act as thermal buffers between the crust and deeper convecting mantle, preventing the melting of the lower crust. Though precise heat flow measurements in Mutuipe-Itaberaba region are necessary to confirm the existence of a thicker lithosphere, a cold root zone extending deep into upper mantle may be invoked as an ideal mechanism against further tectonothermal mobilization of Archean nucleii.

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