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U, Th AND RARE EARTH ELEMENTS IN MESOZOIC THOLEIITE DYKES FROM THE NORTHERN GUIANA SHIELD

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RESUMO

U, Th e elementos Terras Raras foram analisados em diques toleíticos de idade Mesozóica que são intrusivos no Escudo Guiano durante ou pouco antes da separação dos continentes Sul-Americano e Africano. A distribuição dos elementos Terras Raras revela um enriquecimento em Terras Raras leves, ausência de anomalia de Európio e um empobrecimento de Terras Raras pesadas. Esse modelo de distribuição é incomum nos diques toleíticos continentais, basaltos da cadeia Meso-oceânica e basaltos da região do Caribe, mas pode ser comparado com basaltos fora da região da cadeia Meso-oceânica e a toleítos Havaianos. É possível que os magmas foram derivados de uma fonte relativamente não empobrecida antes da separação dos continentes. Valores de U, Th e K/U nas amostras de rocha estão dentro do intervalo geralmente encontrado para rochas basálticas inalteradas. Entretanto as razões Th/U exibem uma tendência diferente dos toleítos modernos que se originaram de uma fonte empobrecida no manto. Essas razões encontradas nos diques Mesozóicos estudados, também suportam a implicação de que o magma foi gerado de uma fonte não empobrecida.

1. INTRODUCTION

At the close of the Paleozoic and beginning of the Mesozoic basaltic dykes and dyke swarms of tholeiitic composition intruded the Guiana Shield with a relatively higher concentration nearer to the present coastal regions. Radiometric dating yielded Permo-Triassic ages for most of the dykes which represent a second major pulse of basaltic dyking on the shield, the first being the much older one of Middle Proterozoic age (PRIEM et al., 1970; GIBBS & BARRON, 1983). Some of the younger basic dykes are to be found along the margin of the Cretaceous Tukutu graben in south Guyana which was partly infilled with tholeiitic basalts (BERRANGE & DEARNLEY, 1975) and is thought to be a failed arm of the Georgetown rift-rift triple junction (BURKE & DEWEY, 1973). In a brief note, CHOUDHURI and MILNER (1971) related the Mesozoic intrusions to the onset of separation of the African and South American continents. On the basis of major and trace element analysis it was previously suggested that the dyke magmas were derived from the flanks of a rising mantle plume that subsequently gave rise to the basalts of the Mid-Atlantic ridge (CHOUDHURI, 1978). Here we examine the U, Th and few rare earth element concentrations for some of the dykes and, although no general conclusions can be drawn at present, an evaluation of the possible nature of the source magma of these dykes is attempted.

2. ANALYTICAL TECHNIQUES

The rare earth elements and U and Th were determined by instrumental neutron activation analysis. The tecnique employed in the determination of U and Th has been discussed in detail in IYER et al. (1984). Due to the lower concentration of U and Th in the samples analysed, the irradiation and counting times were increased to improve the sensitivity of the analytical method. For the rare earth elements Sm, Eu, Yb, Lu and La, about 100 mg each of sample and 50 mg of a standard (BCR-1) were irradiated in polyethylene capsules (9.4 mm diameter, 2.7 mm height) wrapped in aluminium foil and placed in aluminium cans. The irradiation was carried out for a period of eight hours in an average thermal neutron flux of 5×10^{12} n $cm^{-1}sec^{-1}$. One standart was placed between each set of two samples in the irradiation cans. After a cooling time of 200 hours, samples and standards were counted in an Ortec Win-15 Ge(Li) detector system with a resolution of 2.45 keV for the 1332.5 keV peak of ^{60}Co, at a warranted efficiency of 15%. The spectra were accumulated with an Ortec 4096 channel analyser and data reduction achieved by the Ortec Geligam V3D (ORACL) program (Gamma 2.V12). The counting time was generally about 3000 seconds. In the table 1 the gamma ray energies and the half lives of the radioisotopes used for the REE determination are presented (Zaddach, 1973). The error involved in the analysis, expressed as relative standard deviation, was of the order of 10% for Eu, Yb, La and Lu, and about 2% for Sm.

3. PETROGRAFHIC AND CHEMICAL CHARACTERISTICS

3.1. Petrography

All the dykes show characteristic fine to medium grained ophitic to subophitic textures and can be classified as dolerites (European usage) or diabases (American usage). However, since these terms depend solely on the mode of occurrence and texture of the rocks, they are intentionally avoided in the text.

Mineralogically the rocks are made up essentially of plagioclase, pale buff augite and pigeonite, and accessory minerals such as biotite, green amphibole, apatite and micropegmatite which occur in minor amounts; ore minerals present are commonly magnetite and ilmenite besides rare chalcopyrite and pyrrhotite. Olivine occurs as a rare relict mineral enclosed in pyroxenes, often resorbed and altering to iddingsite. It is clear that the rocks are not actually olivine bearing due to evidence of a reaction relationship of olivine with the magma; rather the rocks are saturated tholeiites as can be seen from their micro-pegmatitic residue. Their saturated tholeiitic composition is also confirmed by major element chemical analysis.

3.2. Chemical Signature

In recent years there has been quite a proliferation of geochemical analyses of basaltic rocks in order to determine the origin of their magmas and also to understand the chemistry of their ultimate source, the mantle. For many of the modern basalts their chemistry has been related to their tectonic setting by means of selected variation diagrams using major and trace element concentrations (PEARCE & CANN, 1973; PEARCE et al., 1977). Although these methods are valid for volcanic rocks, they may be applied in a limited sense to other basaltic rocks to enable us to examine at least the "affinity" of the magmas to present day basalts and not necessarily draw conclusions as to their tectonic setting. In the present case a discriminant diagram used by PEARCE (1976) is applied to the Guiana rocks.

Chemically the rock compositions fall in the central field of maximum concentration for tholeiites after LE MAITRE (1976) in a conventional alkali — silica diagram. This indication of saturation leads us to suggest that the olivines were trapped in chilled magmas of the dykes and their rapid ascent prevented complete reaction of olivines which were fractionating in the original liquids.

The continental basalt character of the dykes is brought out by discriminant functions given by PEARCE (1976) (based on eight major oxides) who has applied them to a large number of basaltic rocks of continental, ocean island, ocean floor and island arc settings. It can be seen from the discriminant diagram in Fig. 1 that the Guiana dykes plot in the continental field although some of them possess transitional character as they have compositions similar to low-K tholeiites. Thus as far as bulk compositions are concerned the magmas are in keeping with the continental setting of the dykes. As we shall see however, their rare earth element distribution and U and Th contents deviate from present-day basalts.

3.3. Rare Earth Elements, U and Th

The REE patterns of the dykes are best seen in the usual chondrite normalized diagram and can be compared with examples from literature. The U, Th and REE concentrations are listed in table 2. The overall patterns that emerge, namely moderately inclined, LREE enrichment, slightly HREE poor and lack of Eu anomaly (fig. 2) are unlike continental basalt pattern given in WEDEPOHL (1970), rather they resemble more the REE patterns for Hawaiian tholeiites (BENCE et al., 1975). It was previously thought that dyke magmas originated from the flanks of a mantle plume at the time of continental rifting (CHOUDHURI, 1978). However, there is no similarity of REE pattern to mid ocean-ridge basalts (MORB) that are generated by such plumes, so that any connection between the dykes and ridge basalt magma can be discounted. Moreover, lack of Eu anomaly rules out plagioclase fractionation in the formation in the magmas, and the HREE are not so strongly depleted as to suggest garnet in the residue of partial melting of mantle peridotite in the production of the magmas. For magma generation, we suggest continuous olivine fractionation in rapidly rising liquids as envisaged in the model proposed by O'HARA (1968). It is therefore possible that these magmas with higher concentration of LIL elements (CHOUDHURI, 1978) and LREE enrichment come from a relatively undepleted mantle source in contrast to MORB, although oceanic basalts exist which diverge from the normal MORB pattern (WOOD et al., 1979). Perhaps the closest fit for the observed patterns can be obtained from a flat mantle pattern with subsequent partial melting and fractionation of this relatively undepleted mantle.

3.4. Radioactive Element Distribution

The concentration of U, Th, Pb, Rb and Sr (LILE) in basalts vary widely as a result of partial melting and to some extent crystal differentiation and their concentration provide valuable information regarding the process of magma derivation and the geochemistry of the mantle source region. Tatsumoto (1978) analysed the Th, U contents of oceanic basalts and showed that abyssal tholeiites have low Th/U ratios ranging from 0.65 to 3.0, while alkali basalts generally have ratios greater than 3.3. Tholeiites from Hawaii, Iceland and Oregon have intermediate values. Sinha (1976) derived two distinct linear frends (Th/U against SiO_2) for the modern alkali and tholeiitic basalts and a different trend with a small slope for Archean basalts (fig. 3). Tatsumoto (1978) interpreted the different trend in the Th/U ratios as suggesting that abysall tholeiites originate from a depleted layer, whereas the alkali basalts are derived from a less depleted layer. However in Hawai, where the Th/U ratios are similar for the alkali and tholeiitic basalts, they are assumed to have been derived from a source of less depleted layer.

The U, Th, Th/U and U/K values of the Mesozoic dykes o northern Guiana shield are in the range normally observed for non altered basalt rocks. The K/U ratios are similar to the average basaltic value (6×10^{-5}) as suggested by Heier and Rogers (1963). These values are much lower than the ratios obtained for MORB (Kay and Hubbard, 1978) and tertiary basalts of Baffin bay (O'nions and Clarke, 1972). The higher ratios of the latter are attributed to the effects of sea water interaction and enhanced crustal contamination of uranium.

The Th/U ratios of dykes plot well above the general trend of tholeiites and close to the alkalic and Archean trend (fig. 3). These samples can be compared to the tholeiitic and alkalic basalts of Hawai, whose Th/U ratios range from 2.8 to 6.6. In Hawai the Th/U values and the lead isotope data were interpreted by Tatsumoto (1978) as due to the mixing of two components. Viz. partially melted material from asthenosphere (mantle plume?) and the lithosphere. The lack of lead isotope data and the analytical data of only four samples make it difficult to envisage the type of magma that produced these dykes. However, the radioactive element data lend support to the hipothesis of the derivation of magmas from a relatively depleted source.

4. ORIGIN OF DYKE MAGMAS

Although an interpretation of the nature of basaltic magmas of Mesozoic dykes in Guiana is severely restricted by the small number of samples analysed here, some conclusions can still be drawn regarding their formation. No attempt is made to generalise at this stage, however, and one can only point to the possibility of a wider application of the interpretation when larger number of samples and analyses become available.

On the whole the bulk chemistry of the dykes reflects their continental setting, while there is some divergence with regard to REE, U and Th on the basis of which we provisionally suggest an undepleted mantle source for the magmas. If we accept the mantle plume model for the formation of ocean ridge tholeiites (GAST, 1968) then it is reasonable to assume that such a plume exerted forces for the separation of the continents. In that case the chemistry of the dykes can best be explained according to TATSUMOTO's model (1978) in which mantle convection is envisaged as a cell whose outer parts are depleted in LIL elements and inner parts less depleted, and are responsible for supplying ridge basalts and "hot spot" basalts respectively. It is not difficult to imagine a similar situation beneath the Guiana Shield at the time of continental separation. In this case the dykes could have formed from fractionated magmas derived from the less depleted central portion of a convection cell which would rise plume-like to shallow levels and inject the magma along lines of weakness on the shield. The general validity of this scheme needs to be verified and could eventually carry with it important implications for the generation of basaltic magmas along rifted continental margins.

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TABLE 1. GAMMA RAY ENERGIES AND HALF LIVES OF RADIONUCLIDES USED IN THE DETERMINATION OF R.E.E. BY INAA METHOD.

ELEMENT DETERMINED	RADIOACTIVE NUCLIDE	γ-RAY ENERGY (keV)	HALF LIFE
Sm	^{153}Sm	103	46. 8 h
Eu	^{152}Eu	344	12. 4 y
Yb	^{175}Yb	396	101 h
Lu	^{177}Lu	208	6 - 8 d
La	^{140}La	328 487	40.23 h

TABLE 2. REE, U AND Th CONCENTRATION (ppm) IN MESOZOIC THOLEIITE DYKES FROM GUIANA

SERIAL Nº	ORIGINAL Nº	La	Sm	Eu	Yb	Lu	U	Th	$(La/Sm)_N$	Th/U
YB - 1	67 Sur 19	15	5.9	2.2	2.9	0.54	0. 4	1.5	1.5	3.7
YB - 2	67 Sur 22	16	7.4	2.5	4.0	0,56	0.48	1.9	1.3	3.9
YB - 8	Ac-51-4	11	4.5	1.5	2.3	0.46	0.52	2.4	1.5	4.6
YB - 9	Ac-51-7	10	3.4	1.2	2.1	0.36	0.34	1.5	1.8	4.4
YB -10	Ac-51-8	18	5.2	1.7	2.6	0.50	0.75	3.6	2.1	4.8

Analyses Dr. M.B.A. Vasconcellos IPEN - São Paulo

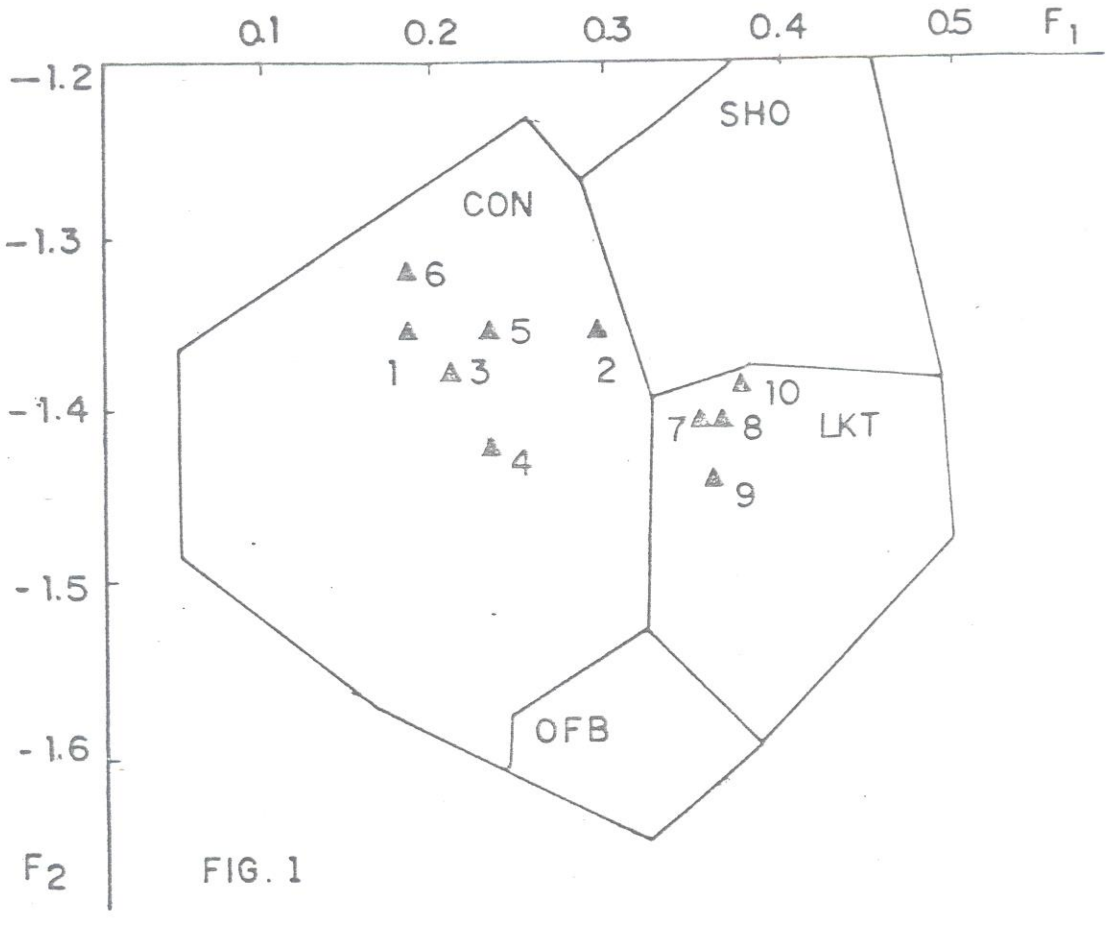

FIG. 1

Fig. 1. Guiana dyke compositons plotted in a discriminant diagram for basaltic rocks after PEARCE (1976) with functions F_1 and F_2 calculated on the basis of major elements. OFB – ocean floor basalts, LKT – low-K tholeiites, CON – continental basalts, SHO – shoshonites (island arc). Serial numbers 1, 2, 8, 9 and 10 correspond to sample numbers 19, 20, AC – 51 – 7 and AC-51.

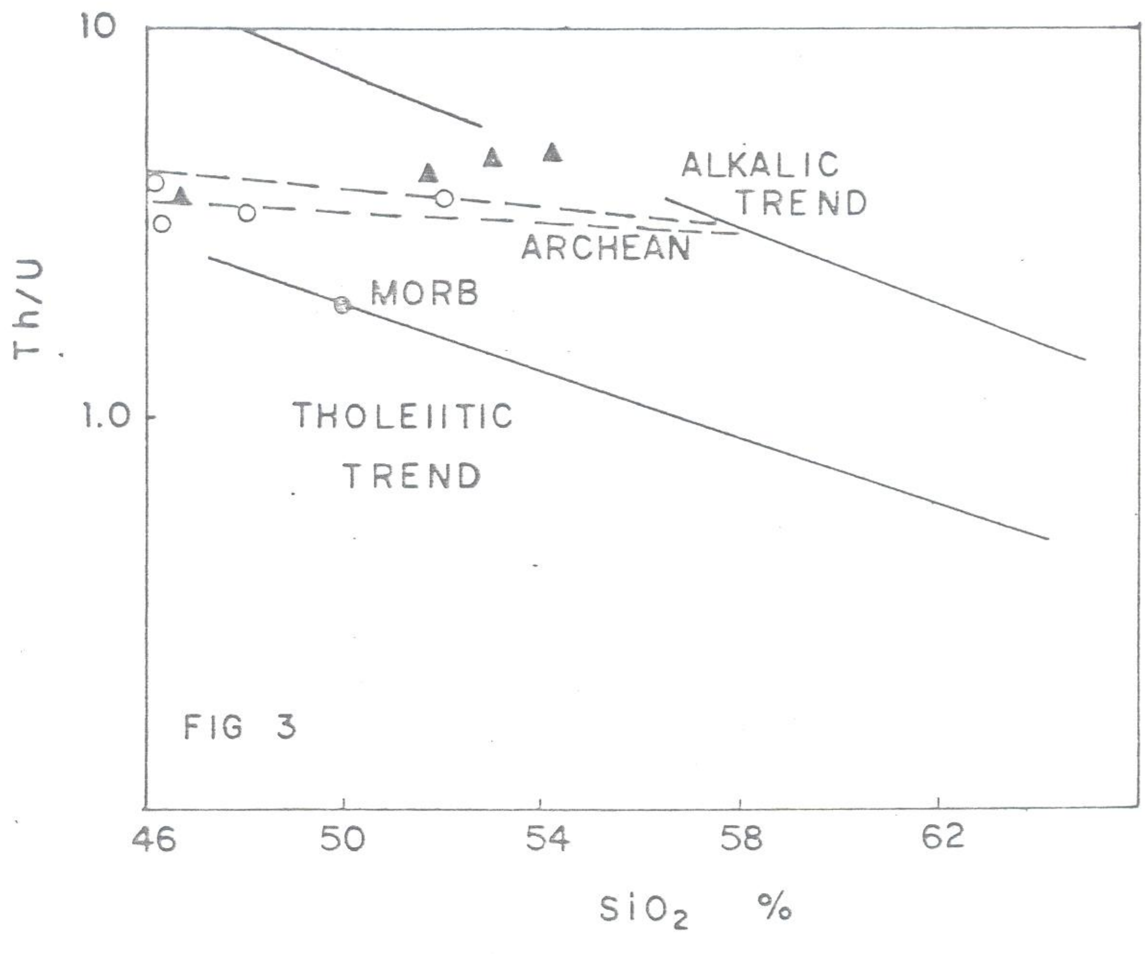

Fig. 3. Th/U ratios compared with MORB (solid circle), tholeiite, alkalic, Archean basaltic rocks and Hawaiian basalts (open circles) from SINHA (1976). Triangles are Guiana dykes of this study.

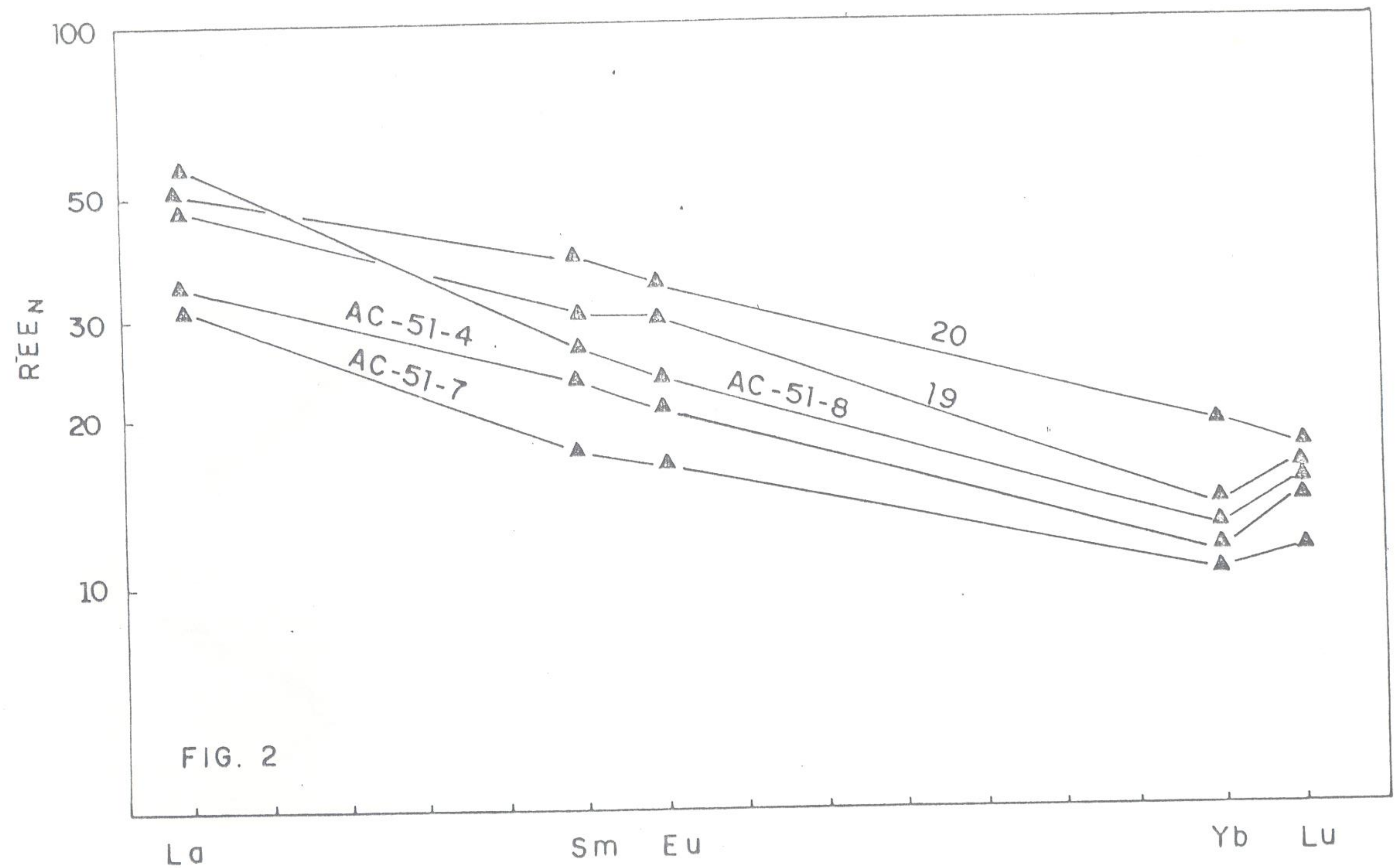

FIG. 2

Fig. 2. Rare earth patterns for Guiana dykes nº 19, 20, AC-51 – 4, AC-51 – 7 and AC-51 – 8 correspond nº 1, 2, 8, 9 and 10 of Fig. 1 (Chondrite normalisation after data from MASUDA et al (1973) which are divided by 1.2 (See Jahn et al. (1980) for explanation).