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NATURE AND POSSIBLE ORIGIN OF BASALTIC MAGMA IN THE PROTEROZOIC OF THE NORTHERN GUIANA SHIELD

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RESUMO

Nos Cinturões de Rochas Verdes (CRV) de idade Proterozóica inferior do Norte da Guiana predominam rochas de composição basáltica, não existindo evidências de extenso vulcanismo basáltico antes dessa época. Um segundo pulso importante de magmatismo basáltico é representado pela Suite de Avanavero com sills e diques de Proterozóico médio. Os CRV têm sido comparados a seqüências de arcos insulares, mas composicionalmente as rochas da seqüência vulcânica diferem dos seus análogos modernos. Em diagramas discriminantes notam-se similaridades entre estas rochas e os basaltos de cadeias meso-oceânicas (MORB) e toleíitos de arcos insulares (IAT), porém existem diferenças significativas nos conteúdos de Ti e Zr, assim como nos padrões de Terras Raras. Um esquema provisório é montado para explicar o magmatismo basáltico, com a devida consideração das suposições e suas incertezas a respeito dos regimes termais no Proterozóico; neste cenário dedicou-se uma ênfase especial às composições dos diques do Proterozóico médio.

ABSTRACT

Rocks of basaltic composition predominate in the volcanic sequences of the Early Proterozoic greenstone belt of northern Guiana, and there is no evidence for extensive basaltic volcanism before this time. A second important pulse of basaltic magmatism is represented by the Avanavero Suite of sills and dykes in mid-Proterozoic times. The greenstone belt has been likened to island arc sequences, but compositionally these basic rocks as well as those of later dykes are different from modern analogues. Similarities which exist between them and mid-ocean ridge basalts (MORB) or island arc tholeiites (IAT) are brought out in discriminant diagrams; and yet significant differences are recorded in their Ti and Zr contents and REE patterns. With due consideration to thermal regimes in the Proterozoic and all the uncertainty that is attached to such assumptions, a provisional scheme is set up to account for the basaltic magmatism; in this scenario special emphasis is given to the composition of the mid-Proterozoic dykes.

INTRODUCTION

Basaltic rocks are common in the Early Proterozoic granite-greenstone terrain of the Guianas. In terms of volume, the large majority makes up the greater part of the volcanic sequences of the greenstones (GIBBS, 1980), while a still significant proportion occurs as intrusive complexes and bodies, some associated with the volcanics and others of later formation. Of these types, mafic-ultramafic complexes, gabbroic intrusive bodies and unmetamorphosed basaltic dykes are the most frequent and have been dealt with briefly by BOSMA et al. (1983). It has been shown by GIBBS (1980, 1984) that the volcanic sequences of the Guianas greenstone belt strongly resemble island arc volcanic being very similar to the Archaean Abitibi greenstone belt of Canada. If we therefore consider the formation of this part of the Guiana Shield in Proterozoic island-arcs, a comparison of the basaltic rocks of this region carries with it interesting implications for magma generation at that time. A model is proposed for this environment with reference to the basaltic rocks which occur as a part of the volcanic sequences and those that form the unmetamorphosed mid-Proterozoic dykes.

BASALTIC ROCKS IN NORTHERN GUIANA

In their description of the greenstone belt of the northern Guiana Shield, GIBBS (1980), and Bosma et al. (1983) stress the dominance of basaltic rocks in the volcanic sequences which are characterized by magnesian series, tholeiitic and calc-alkaline series. Typically, the volcanic rocks commence with tholeiites at the base of the pile and pass on to calc-alkaline towards the top. There are the major occurences of basalts in the belt which has been compared to Phanerozoic island arcs by these authors. Besides these volcanics, several gabbroic intrusive bodies also occur - the De Goeje gabbros of Suriname belong here, but the mafic to intermediate rocks of these bodies show calc-alkaline trends and are thought to be cogenetic with acid to intermediate volcanism (KROONENBERG, 1976; BOSMA et al., 1983). Widespread basic magmatism is therefore restricted to the Early Proterozoic (CHOUDHURI, 1980). The next important pulse of basic magmatism came in mid-Proterozoic times with outpouring of large amounts of magma in the form of thick sills and dykes of the Avanavero Suite which is now taken to include the former Roraima Intrusive Suite of Guyana (GIBBS and BARRON, 1983). Excluding the gabbroic intrusives, a comparison of the geochemistry of these basaltic rocks is made here. Although such reflections give rise to several problems as to the formation and consolidation of the Guiana Shield in the Proterozoic, not all these questions can be addressed here being somewhat beyond the scope of the present contribution. We shall restrict the discussions to the generation of basaltic magma keeping in mind the island arc model first developed by GIBBS (1980). Back-arc models for greenstone belts were also proposed by WEAVER and TARNEY (1979) and TARNEY and WINDLEY (1981), but it is not certain whether they are universally applicable.

CHEMICAL FEATURES OF BASALTIC ROCKS-VOLCANICS AND DYKES

It has been shown that in many instances basaltic rocks possess geochemical characteristics which can be related to specific tectonic environments in which these magmas have formed (PEARCE and CANN, 1973). Although these correlations might hold good for younger geological periods, difficulties arise in attempting to extrapolate present day data to Precambrian times for which the tectonics are still poorly understood. On the whole, basaltic rocks from the early Precambrian are chemically similar to those we find today and in recent geological settings, but somehow their major and trace element contents and their

REE character do not fit in very well with the geochemistry of these settings. Rather, these ancient basaltic rocks are frequently similar to each other than to their modern counterparts (see e.g. GILL and BRIDGWATER, 1979). As we shall see presently, in this respect the basaltic rocks of the Guiana Shield are no exception.

In their synthesis on marginal basins TARNEY and WINDLEY (1981) have pointed out that modern basalts from back-arc spreading centres include types equivalent to N-type and E-type MORB with low LIL (large ion lithiphile) elements and higher LIL elements respectively. Other basalts in back-arc basins have moderately high LIL, K, Rb, Sr, Ba and REE, but without the enrichment of HFS (high field strength) elements as in the E-type MORB. Transitional types occur where back-arc spreading took place by splitting of a calc-alkaline volcanic arc. These features then represent the overall chemical signature of basaltic rocks in many island arcs.

Compared to the above geochemical signature the rocks from Guyana are however different, as has been shown by GIBBS (1980): the Guyana tholeiitic basalts have lower alkalis, Sr and Al_2O_3 than island arc tholeiites, while their Ni, Cr and Co are higher. In the same way, the basalts and andesites of the calc-alkaline series have higher Ni and Cr than island arc tholeiites but distinctly lower Zr. Such features are shared by the greenstone belt rocks from the Superior Province of Canada. Volcanic rocks from the Suriname belt are also very similar inasmuch as they have lower Ti and Zr than MORB, higher Cr than island arc, and REE like those of Archaean basalts rather then MORB, according to BOSMA et al. (1983). On the basis of these chemical characteristics the above authors suggest a more primitive island arc environment than we find in modern arcs.

The basaltic magmas which fed the mid-Proterozoic sills and dykes subsequent to the Trans-Amazonic orogeny in the greenstone belt also differ from their modern analogues - they have typically low Ti, Zr and P_2O_5 just as those of the greenstone belt volcanics. Some of these characteristics are well brought out in pertinent discriminant diagrams, which follow. For a general comparison averages of basaltic rocks from various environments are given in Table 1.

BASALT COMPOSITIONS IN DISCRIMINANT DIAGRAMS

Chemical compositions of basaltic rocks can be plotted in several discriminant diagrams in order to relate various groups to known tectonic settings. Only two such diagrams were selected to focus on the salient features of the Guyana rocks in relation to modern examples from island arcs and ocean ridge and floor. One of them is the multi-element discriminant of PEARCE (1976) and the other is an FeO-MgO-Al_2O_3 triangle; a third three dimensional construction to illustrate K_2O-Ti-Zr variation has also been used with data from literature and from Guyana. Rb-Sr variation and REE patterns are used to complete the picture.

Multi-element variation

The geochemical nature of the basaltic rocks from Guyana is clearly seen in the treatment of their major elements according to the factor analysis of PEARCE (1976), and the different groups are shown in Fig. 1 - these are the greenstone belt magnesian volcanic series and tholeiites of GIBBS (1980) and mid-Proterozoic basaltic dykes (analyses from AC on request). All three groups occupy the field of low potassium tholeiites (LKT), and this is not surprising for the volcanics from the greenstone belt but it is unusual for the continental dykes. Evidently the dyke compositions are distinct from present day continental tholeiites. Some of them scatter away from the tholeiite field of GIBBS (1980) possibly due to their own differentiation from their parent liquids.

In a FeO-MgO-Al_2O_3 plot PEARCE et al. (1977) showed a way of discriminating modern basic volcanics on a statistical basis; the plot was however not very successful for ancient rocks, and herein lies the danger of deducing tectonic settings for Precambrian rocks. For example, in spite of the fact that Archaean tholeiites plot in the field of ocean ridge basalts (MORB), CONDIE (1981) stresses the need for caution in interpreting tectonics on such criteria alone. Interestingly enough, the basaltic rocks from Guiana, that is those from the volcanic sequence as well as most of the dykes, fall in the ocean ridge field with the exception of a few compositions which fall in the continental category (Fig. 2). Employing this diagram we therefore see that the rocks have affinities with mid-ocean ridge basalts (MORB - OFB in Fig. 2) as well as with island arc tholeiites (IAT - LKT in Fig. 2).

K-Rb-Sr variation

Concentrations of all three of these incompatible elements increase in the course of differentiation of basaltic magma, but whereas K/Rb ratios remain virtually constant in the process, Sr/Ca ratios increase due to increase in Sr and its principal association with Ca in plagioclase. CONDIE et al. (1969) recorded varying trends involving relations between these elements and showed that there exists a normal and a Sr depletion trend - the latter seen to be a characteristic of Precambrian Wyoming diabases. He ascribed the latter trend to a possible mechanism of plagioclase fractionation. Lately, CONDIE (1981) has discarded this idea on the basis of rare earth element (REE) patterns and prefers to account for the trend by some process of Ca removal either during metamorphism or alteration.

The mid-Proterozoic dykes also show a Sr depletion trend, as can be seen in Fig. 3 in which other trends are also plotted for comparison. In this case, however, both the plagioclase removal hypothesis and alteration have to be rejected as possible processes. Firstly, as we shall see later on, REE patterns do not support fractionation of plagioclase; secondly, the rocks are entirely fresh without the least sign of alteration. An explanation might be sought in relatively rapid increase in K and Rb concentrations affecting the overall Sr trend, perhaps due to the original enriched nature of the mantle source. The observed trends are clearly different from those of either MORB, IAT or continental tholeiites and thus diverge from any rigid classification which one might be inclined to impose on Precambrian tholeiites.

K_2O-Ti-Zr variations

Besides belonging to the group of incompatible elements, Ti and Zr are also considered immobile with respect to later alteration or metamorphism of mafic and ultramafic rocks. Apart from this, the unaltered and unmetamorphosed nature of the mid-Proterozoic basaltic dykes is sufficient ground for comparison of their Ti and Zr contents with other basaltic rocks. The variations of these two elements in conjunction with K are divergent in MORB and IAT: MORB are relatively low in K and higher in Ti and Zr. Fig. 4 takes into account all three elements in different basalt groups including E-type MORB. Since Ti and Zr fractionate together, their variable ratios in basaltic magmas must be specific for their respective mantle sources. The basaltic rocks from Guiana follow the low-Ti-Low-Zr trend in such a diagram.

RARE EARTH ELEMENTS

In the recent voluminous literature on basaltic and andesitic magmas REE patterns have frequently been used for modelling and characterization of these magma types. CONDIE (1981) summarizes several REE patterns for Archaean rocks which can be useful for purposes of comparison. Chondrite normalized REE patterns for mid-Proterozoic Guiana dykes are shown in Fig. 5. Because of the common behaviour of REE in any specific magma, features such as light REE (LREE) enrichment or depletion or heavy REE (HREE) depletion reflect the inherent nature of the source of the magma and are only slightly modified by degree of partial melting of the source or subsequent differentiation. The LREE enriched pattern of the dykes therefore reflects the source composition and we are led to suggest an enriched source for their magmas; the steeper slopes of the upper curves in the figure could be the result of differentiation from parent magma. Furthermore, the absence of an Eu anomaly leads us to discard the idea of plagioclase fractionation to explain the Sr depletion trend mentioned earlier on.

The REE distribution of the dykes is unlike MORB or continental tholeiite, rather they share the characteristics of Archaean tholeiites from the Canadian greenstone belts and the greenstone belt of Guiana where the dykes occur. This has far-reaching implications for the production of these magmas, since we have to assume a relatively enriched mantle source which was still left over after the production of the volcanics of the early Proterozoic greenstone belt. In the context of the thermal regime at that time, on which we can at the moment only speculate, several similar models for an enriched mantle source can be invoked in this case.

THERMAL REGIMES AND MAGMA MODELS

If we agree to the model of thermal regimes put forward by DAVIES (1979) in which the Archaean and present day geotherms are compared, the former being significantly higher though buffered by a thick root sone which prevents melting of deep crustal levels, then perhaps Early Proterozoic thermal gradients may have been somewhere between these two. This could be the case particulary in non-sialic environments as in the island arc paradigm of Guiana. Higher thermal gradients close to or greater than present-day oceanic geotherms would facilitate mantle melting and magma production in the Guiana island arc.

An analysis of the formation of ultramafic and basaltic komatiites by MCIVER and LENTHAL (1973) suggests high-pressure melting of mantle sources. Consequences of this kind of magma production are illustrated in Fig. 6 in which compositions of relevant rock type are projected from the clinopyroxene point in the CaO-MgO-Al_2O_3-SiO_2 (CMAS) tetrahedron on to the M-S-C_3A plane after the method of O'Hara (1968). The Guiana basaltic dykes fall in the low-pressure field which like the basaltic komatiites of these authors results from olivine and orthopyroxene fractionation along the advanced partial melting line (APM) of four phase mantle peridotite. Considering the chemical similarity of the Guiana dykes to Archaean tholeiites, this comparison seems to be valid for the process of magma generation.

For magma generation involving an enriched mantle source we must look for schemes such as those established by TATSUMOTO (1978), RINGWOOD (1985) and MORRIS and HART (1983) all of which propose some kind of mantle heterogeneity, either in the form of convection cells or as dispersed local regions of enriched mantle which on melting yield the relevant magma composition. In principle, all these models are similar. For the Guiana rocks one would have to assume a greater quantity of enriched mantle regions (as loosely scattered and isolated mega-blobs) than envisaged by MORRIS and HART (1983) for present-day island arcs, and this assumption would fit very well the requirements of chemistry as invoked by BOSMA et al. (1983).

As regards the tectonic environment of an island arc-subduction combination, the higher isotherms in the mantle wedge (following the various thermal models proposed by WYLLIE, 1984) should give way to somewhat lower ones in the post-Trans-Amazonic Guiana Shield whereby the still warm mantle and cooler subducting crust could induce melting in enriched portions of the mantle to give the dyke magmas. The hypothesis put forward here is not unlike that of CONDIE (1981) for Archaean subduction, but several other features should in addition be borne in mind. Some of these are the tectonic environment, the magma composition and the possible enriched source regions in an overall depleted mantle. As it standes at present, the model needs further elaboration in order to trace the history of magma production more completely.

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FIGURE CAPTIONS

Fig. 1. Discrimination of basalt types based on factor analysis of PEARCE (1976): OFB - Ocean floor basalts; WPB - within plate basalts; LKT - Low potassium Tholeiites; SHO - Shoshonites; a and b are fields of Tholeiitic basalts and magnesian series volcanics from the Guyana greenstone belt from GIBBS (1980), unmarked field enclosed by dashed line is for mid-Proterozoic basaltic dykes.

Fig. 2. Distribution of ocean ridge and floor basalts (1 & 2), orogenic (3), continental (4) and spreading centre basalts (5) after PEARCE et al (1977). Vertical to diagonal hachure anti-clockwise are Tholeiites, magnesian and cak-alkaline series from GIBBS (1980). Dots are individual analyses for mid-Proterozoic dykes.

Fig. 3. K-Rb-Sr variations for A - Antarctic dolerites, B - Ocean floorbasalts, C - Continental, island arc and ocean island basalts, D - Mid-Proterozoic basaltic dykes from Guiana with a distinct Sr - depletion trend.

Fig. 4. K_2O-Ti-Zr variation for I - island arc, E-E-type MORB and N-N-type MORB. Guiana dykes fit the I trend.

Fig. 5. Chondrite normalized REE patterns for basaltic dykes from Guiana; nº 1 and 15 are probably differentiated (for details see text); dashed line is envelope for greenstone belt Tholeiites from GIBBS et al. (1984).

Fig. 6. Clinopyroxene projection of ultramafic (uk) and basaltic komatiites (bk) in the CMAS tetrahedron (inset) after MCIVER & LENTHAL (1973). Abreviations: CMAS = CaO-MgO-Al_2O_3-SiO_2; En = enstatite Fo = forsterite, Di = diopside, OPX = orthopyroxene, OL = olivine, APM = line of advanced partial melting of mantle periodotite, TD = Thermal divide at low pressures; numbers in triangle are pressure regimes - 1 atm and the remaining in kb; dashed lines meet at isobaric invariant points where crystals and liquid coexist, (for details see text).

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TABLE 1

Comparison of some basaltic rock types

	1	2	3	4	5	6
SiO_2	49,0	50,1	51,1	49,5	52,3	50,36
TiO_2	1,44	2,17	0,86	1,46	0,99	2,37
Al_2O_3	12,07	14,0	16,6	16,8	14,91	14,13
Fe_2O_3 FeO	5,0	13,5	12,3	9,60	11,06	13,18
MnO	0,15	0,14	0,17	0,12	-	-
MgO	7.07	6,46	5,86	7,35	6,73	4,96
CaO	9,43	9,82	10,8	11,60	10,07	10,04
Na_2O	2,18	2,54	1,96	2,77	1,61	1,93
K_2O	0,95	0,8	0,44	0,17	0,83	0,79
P_2O_5	-	-	-	-	0,12	0,27

1, 2, 3 & 4. Precambrian diabase from Wyoming, continental, island arc and oceanic tholeiites (CONDIE et al., 1969); 5 , 6 average of Precambrian dykes and Mesozoic dykes from Guiana (analyses AC).

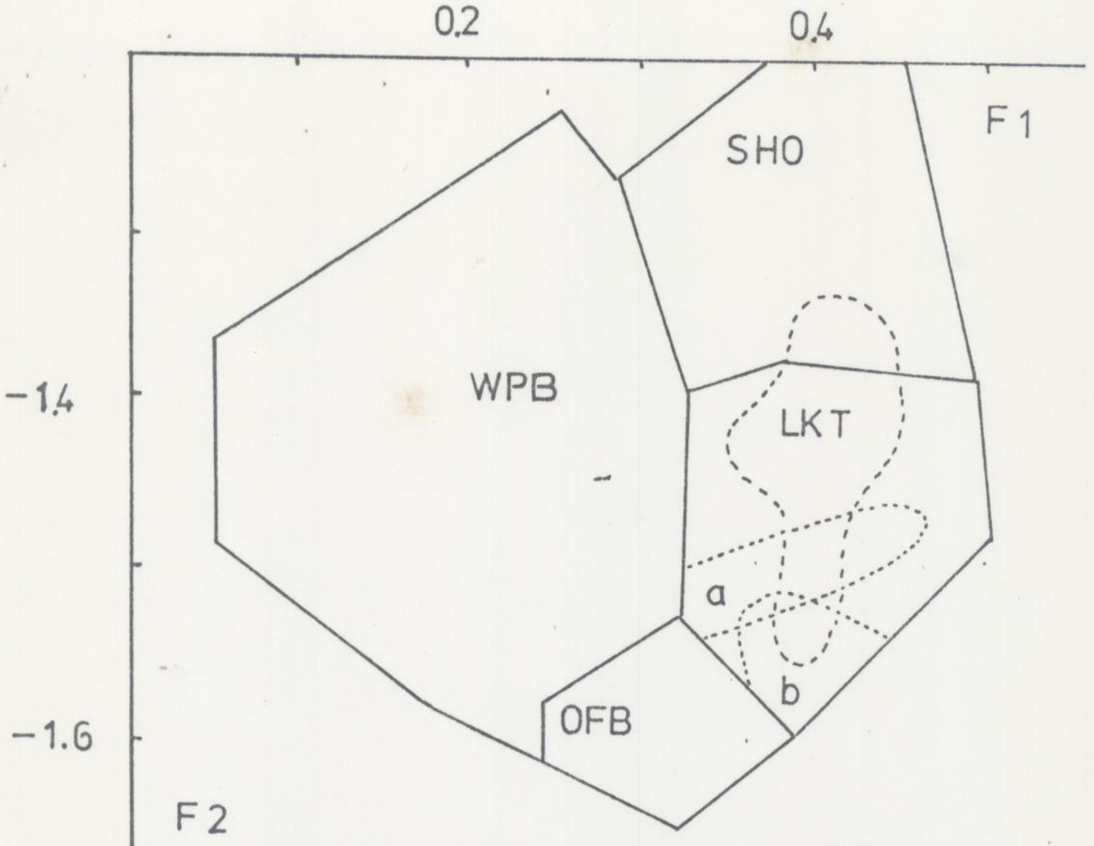

FIG. 1

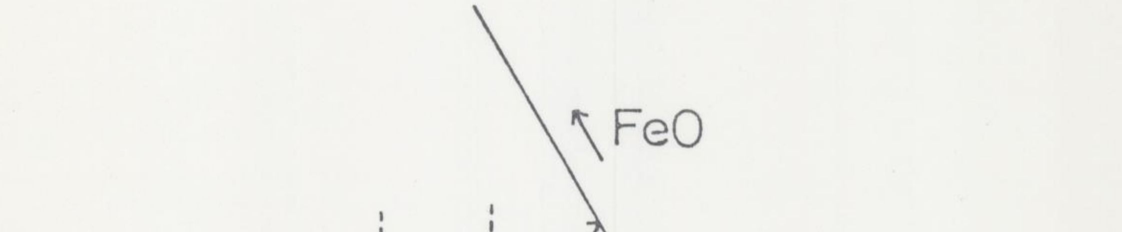

FIG. 2

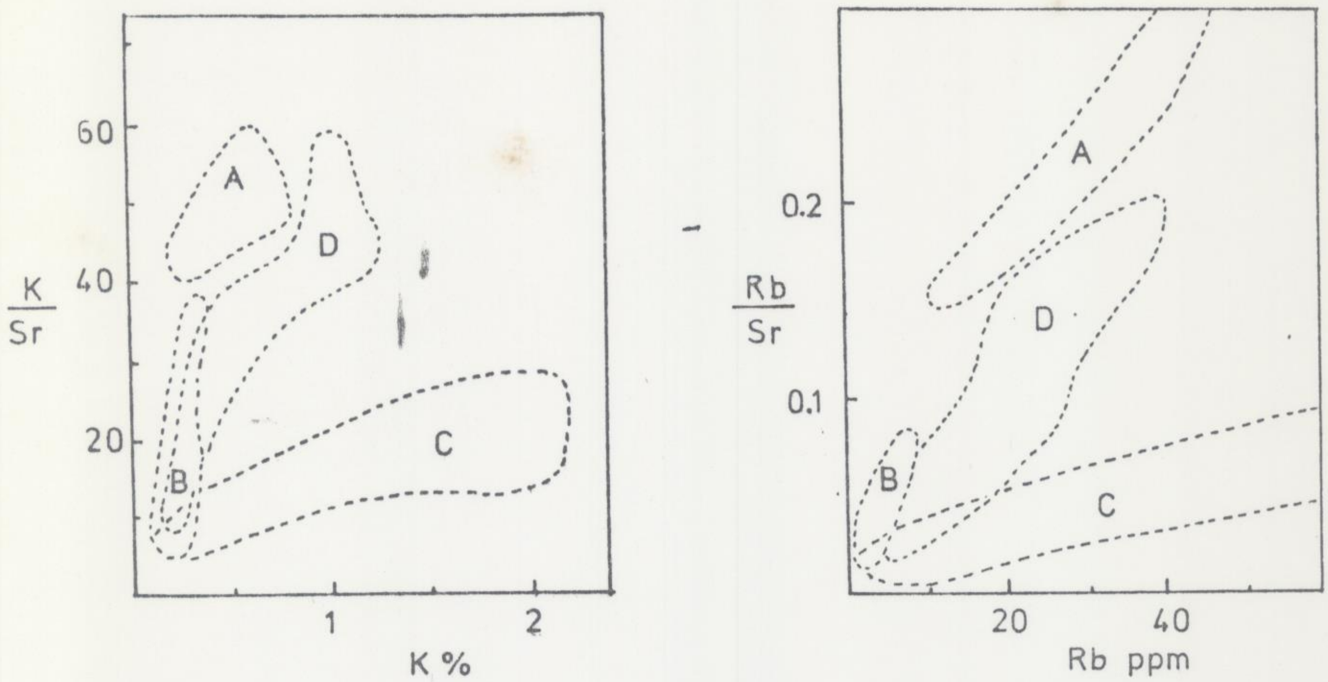

FIG. 3

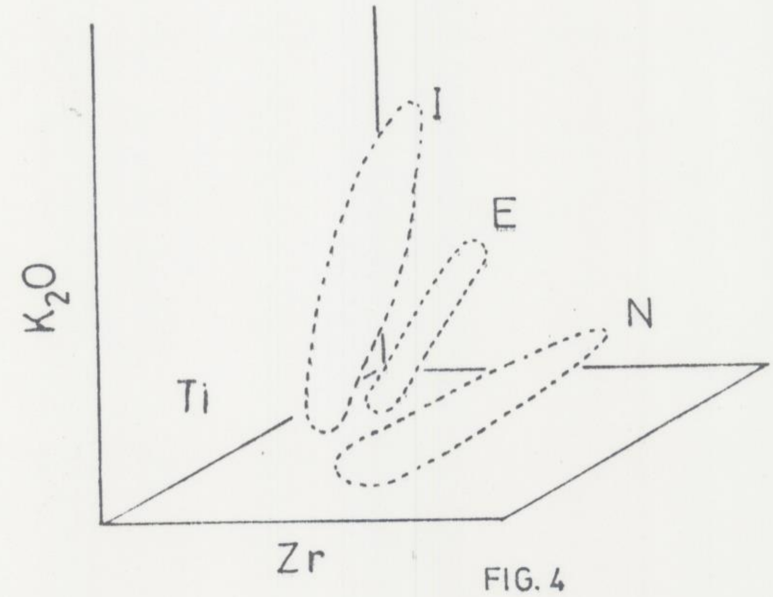

FIG. 4

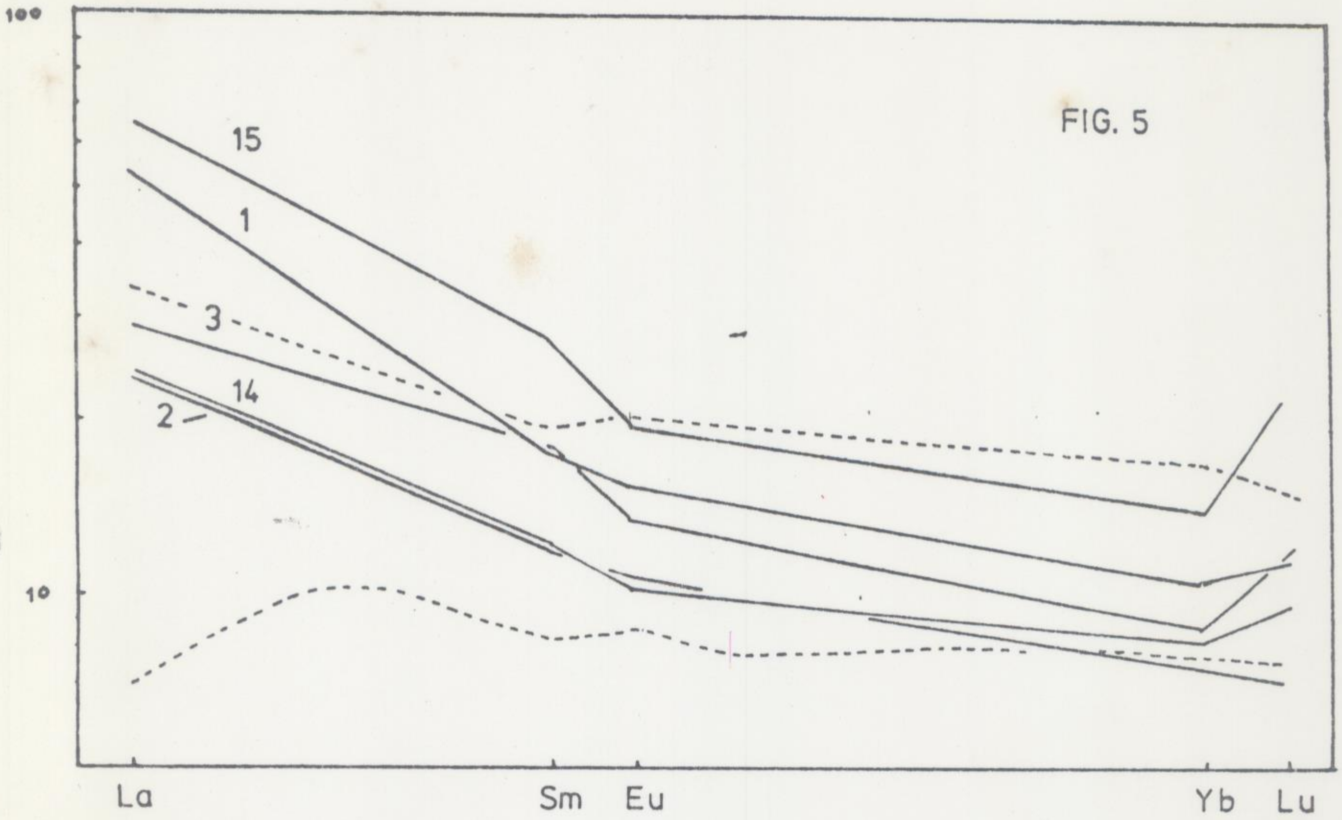
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FIG. 5

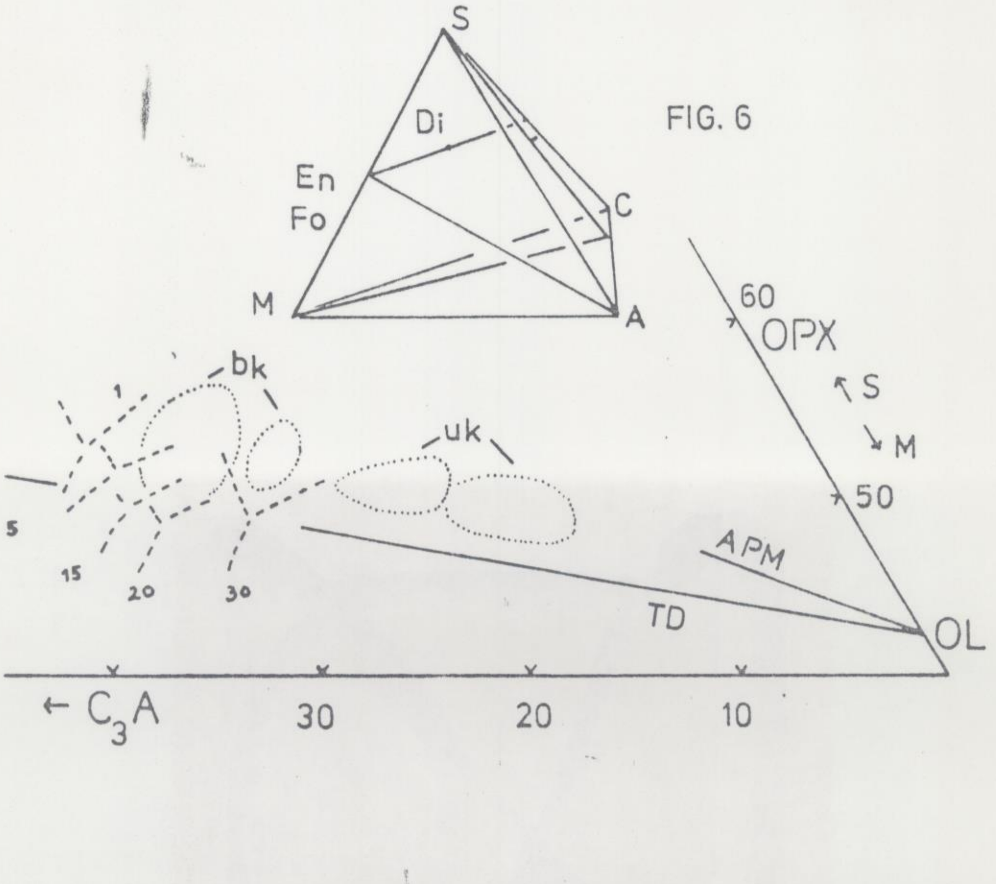
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FIG. 6