Low-K granitoids from the Western Cordillera of Colombia.

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ABSTRACT

We report preliminary petrological and geochemical data from low-K granitoids from the Western Cordillera of Colombia. These rocks are intruded into a massive sequence of low-K tholeiitic basalts but the available age data indicate that both the volcanics and the intrusive rocks are of Upper Cretaceous age. Geochemically the granitoids most closely correspond to oceanic VAG types as defined by PEARCE *et al.* (1984) and they could possibly represent discrete magma phase from that which gave rise to the basalts.

RESUMEN

Se anuncian datos petrológicos y geoquímicos preliminares de granitoides bajos en K de la Cordillera Occidental de Colombia. Estas rocas intruyen secuencias masivas de basaltos toleíticos bajos en K pero los datos disponibles acerca de las edades indican que tanto las vulcanitas como las rocas intrusivas son de finales del Cretácico. Geoquímicamente los granitoides corresponden más estrechamente con tipos oceánicos VAG tal como los definen PEARCE et al. (1984), y podrían representar una fase discreta del magma que dio origen a los basaltos.

INTRODUCTION

The Western Cordillera of the Northern Andes (GANSSER, 1973) is made up of a composite Meso-Cenozoic orogenic belt which extends from approximately 3°S in Ecuador to at least 8°N in Colombia (fig. 1). The geology of this belts is complex (McCOURT, *et al.*, 1984; FEININGER and BRISTOW, 1980) but, in Colombia, it consists essentially of an Upper Cretaceous sequence of basic volcanic rocks, the Diabase Group[2], which is interstratified with sediments and low grade metasediments (BARRERO, 1979; NELSON, 1957; MILLWARD, *et al.*, 1984; ASPDEN, 1984) (fig. 2). To the west this sequence is overlain by thick, unmetamorphosed, Tertiary sediments and its eastern limit is defined by the Cauca-Patia fault zone, along which are found several bodies of ophiolitic rocks (ESPINOSA, 1980).

1) British Geological Survey, Overseas Directorate, Keywort.
2) Following recent recommendations the stratigraphic nomenclature of the Western Cordillera, in the Department of Valle del Cauca, has been revised and, on the most recently published maps, the basalts of the Western Cordillera are referred to as the Volcanic Formation.

Geophysically the Western Cordillera is characterized by large, positive Bouger gravity anomalies which are interpreted to indicate that it is underlain by high density, oceanic crust (CASE, et al., 1971, 1973; MOONEY *et al.*, 1979; FEININGER, 1977). The volcano - sedimentary succession in thought to be part of a suspect terrane which was accreted onto the western margin of NW South America in the Lower Tertiary (McCOURT, *et al.* 1984). The results of geochemical studies, carried out within this belt, have been interpreted to indicate that the volcanic rocks were formed in either an island-arc or ocean basin environment (HENDERSON, 1979; BARRERO, 1979; MILLWARD, *et al.*, 1984).

In the Cali area the main outcrop of the Diabase Group lies to the east of the Río Bravo fault (fig. 2) and consists essentially of a thick sequence of basalts which have undergone low-grade (burial) metamorphism (BARRERO, 1979; RODRIGUEZ, 1981). Pillow lavas are common and various sedimentary horizons, some of wich are laterally persistent (e.g. the Espinal Formation, fig. 2), are also present. Based on the findings of a 4-year, joint BGS-INGEOMINAS, regional mapping project, the Diabase Group, to the east of the Dagua - Calima fault (fig. 2), has been shown to contain a number of intrusive bodies. The mejority of these intrusions are gabbroic in composition (ASPDEN, 1984; BARRERO, 1979), however substancial ammount of granitic material are also present. In particular granitic rocks are known to occur both within the composite, gabbroic-leucotonalitic, El Tambor Stock and also, further to the east, as a series of felsite dykes and plugs(the Vijes Felsites) (McCOURT *et al.*, 1984a; ASPDEN, 1984) (fig. 2). The presence of these granitoids could have important implications when considering the origin of the Diabase Group basalts.

AGE OF THE WESTERN CORDILLERA

Due to their generally low K_2O content the basalts of the Western Cordillera are difficult to date by direct means. Fortunately however, as noted above, the Diabase Group does contain various sedimentary intercalations, some of which have yielded both macro and micro fossils. Within the Cali sector, immediately to the south of Vijes (fig. 2), ammonites of Turonian to lower Coniacian age, have been found (NELSON, 1957; BARRERO, 1979). ETAYO *et al.* (1982) have also reported radiolarian ages "no older than Turonian" from a sequence of pillow lavas, tuffs and cherts which are exposed to the NE of Loboguerrero and similarity, "post- Coniacian" fossil ages (quoted in BARRERO, 1979) have been obtained from the Espinal Formation (fig. 2). Immediately to the north of the area shown in figure 2, ETAYO *et al.* (1982), found various marine fossils within the Western Cordillera sequence which they considered to range from Turonian to Maastrichtian in age. While to the SW of Cali, various fossiliferous horizons from the Ampudia Formation (VERDUGO and ASPDEN, 1984) have yielded datesthat vary from Coniacian to Maastrichtian (KEISER, 1954; ORREGO, 1975).

Regional considerations led McCOURT and ASPDEN (1983) and McCOURT *et al.* *(1984)* to suggest that the entire cordillera, in both Colombia and Ecuador, is likely to be younger than approximately 120 Ma. Similarily ALVAREZ (1983), after reviewing much of the available fossil evidence, particularity from norther and central Co-

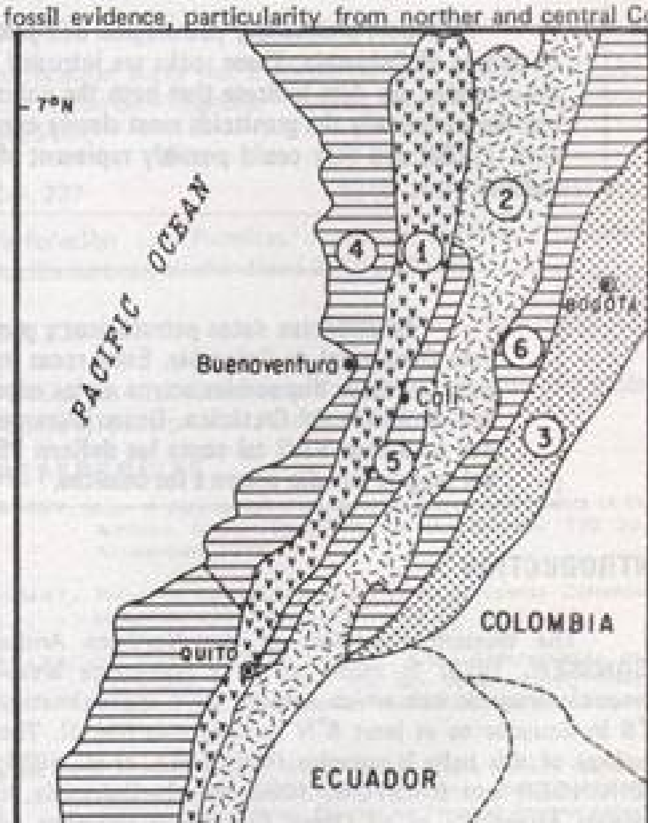

FIG. 1: Generalized physiographic map of Western Colombia and Ecuador. 1 = Western Cordillera; 2 = Central Cordillera/Cordillera Real; 3 = Eastern Cordillera (Colombia); 4 = Coastal Plain; 5 = Cauca - Patía Valley; 6 = Magdalena Valley.

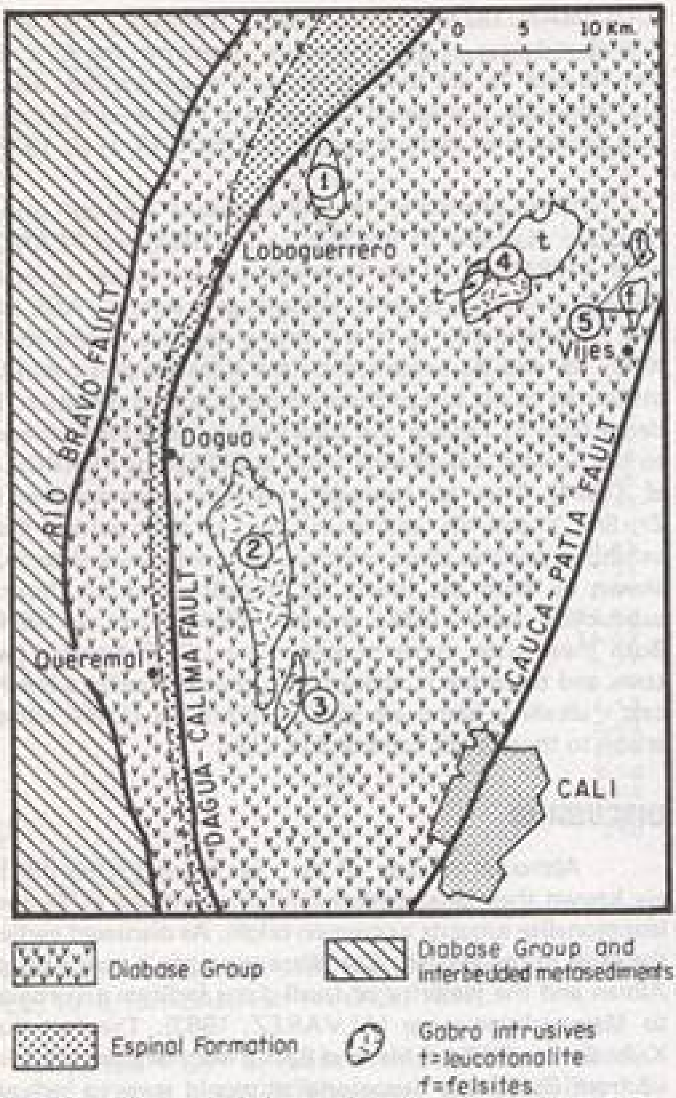

FIG. 2: Simplified geological map of the Western Cordillera of Colombia in the area NW of Cali showing the distribution of the main intrusives after ASPDEN *et al.* (1984) and McCOURT *et al.* (1984a). 1 = Zabaletas Stock; 2 = El Palmar Stock; 3 = El 18 Stock; 4 = El Tambor Stock; 5 = Vijes felsites.

lombia, concluded that the sedimentary rocks of the Western Cordillèra were exclusively Upper Cretaceous and these findings are in agreement with those of BARRERO (1979), who considered thar the tholeiitic volcanism in the Cali area was also of this age.

In summary therefore, although further, more detailed work is required, based on the information which is currently available, it can be concluded that the mejority of the Western Cordillera is undoubtedly post Aptian/ Albian in age. It should be pointed out however, that in various publications dealing with the Western Cordillera a Barremian age is often cited. This age, originally quoted as Barremian to Aptian, is in fact based on fossils which were originally collected from the Central Cordillera (GROSSE, 1926) and so its bearing on the age of the Western Cordillera is open to questicn.

THE EL TAMBOR LEUCOTONALITE AND VIJES FELSITES

PETROLOGY

The poorly exposed El Tambor Stock is a composite leucotonalitic/gabbroic intrusion which has a probable outcrop area of approximately 30 km² (fig. 2). In spite of the extensive lateritic cover, the presence of gabbro xenoliths in the leucotonalite, and the occurrence of leucotonalitic and aplitic dykes within the gabbro, indicate that the gabbro was the earliest phase to be emplace.

The leucotonalite (trondhjemite) varies from coarse to very fine grained and consists of quartz, plagioclase, amphibole and biotite. Opaques, sphene, clinozoisite and apatite are present as accessories. Quartz and the mafic phases constitute up to 40 % and between approximately 10-15 % (modal) of the rock respectively. The plagioclases are euhedral to anhedral and variably corroded. Saussuritization is generally restricted to the An-rich cores or the An-rich oscillae. Compositions vary from at least An_{60} in the cores to An_{30} at the margins. Small, late stage, unzoned crystals have oligoclase to andesine compositions. Strongly pleochroic hornblende occurs as irregular crystals or, commonly, in aggregates which are often associated with sparse crystals of biotite. Ferrohastingsite may also be present in some section (D. MILLWARD, unpubl. data).

The Vijes Felsites are located along the eastern flank of the Western Cordillera (fig. 2) where they occur as a well exposed belt of plugs, sheets and dykes which intrude the basalts of the Diabase Group. The belt is orientated in a north-south direction and has a maximum length of approximately 18 km.

The felsites are crypto- to microcrystalline, aphyric to porphyritic and spherulitic. They contain up to 5 % of quartz and plagioclase phenocrysts. The former occur as angular, subhedral crystals which are typically corroded, whereas the latter are normally seen as saussuritized, subhedral to euhedral laths or aggregates. Such aggregates may also be associated with interstitial chlorite, epidote/clinozoisite and rarely, pumpellyite. Groundmass textures and grain size vary considerably but they generally consist of crypto- to microcrystalline quartz and feldspar and occassional spherulites. Small ammounts of chlorite are present and some of the quartz phenocrysts are cut by fractures, along which recrystallization of quartz has occurred (MILLWARD, in press).

AGE

Samples collected from the El Tambor leucotonalite yielded a 12-point Rb-Sr isochron which defined an age of 94 ± 16 Ma. K/Ar analyses however, carried out on hornblende separates, yielded ages of 84 ± 2 Ma. and 83 ± 3 Ma. (BROOK, 1984). Although normally a more accurate indication of the age would be expected from the Rb-Sr isochron, in this instance, the relatively low Rb concentration, together with the small range in Rb/Sr ratios, results in a whole-rocks age with a relatively poor precision. Hence the more precise K/Ar dates are preferred as the best estimate of the crystallization age for the El Tambor Stock (BROOK, 1984).

Due to their very low K_2O content it has not proved possible to obtain reliable K/Ar dates from the Vijes Felsites an their precise age is unknown. The presence however of felsite pebbles in the basal portion of the oligocene to Lower Miocene, Vijes Limestone Formation (BÜRGL, 1961; SCHWINN, 1969) indicates a minimum Lower Tertiary age for these intrusions.

GEOCHEMISTRY

The analysed samples from the El Tambor leucotonalite and the Vijes Felsites (tab. 1) are characterized by low K_2O and distinctive REE patterns that show LREE enrichment and moderate to large negative Eu anomalies (fig. 3). Geochemically they are very similar to granitoids described from oceanic environments by COLEMAN & PETERMAN (1975) and the leucotonalite has the essential mineralogy of a plagiogranite in that it consists of sodic plagioclase, quartz, hornblende and minor biotite. In detail the LREE enrichment patterns of El Tambor and Vijes suggest an affinity with ocean crust and back-arc basin plagiogranites (ALDISS, 1981; SAUNDERS *et al.*, 1979) rather than typical ophiolitic plagiogranites, which are normally LREE depleted (COLEMAN, 1977; ALDISS, 1981). However their absolute abundances of the "immobile" elements, the REE, Zr, Th, Nb and Ta, are too low for such plagiogranites, which are generally considered to represent high-level fractionation products of mafic magmas (SAUNDERS *et al.*, 1979).

When plotted on the multi-element "granite" discrimination diagrams of BROWN *et al.* (1984) and PEARCE *et al.* (1984) (fig. 4) the Colombian rocks appear to be similar to primitive, oceanic, volcanic arc granites (VAG); and this is particularily so if the strong negative anomalies in K_2O, Rb and Ba exhibited by the Vijes samples could be attributed to the loss of these elements during alteration. In detail both El Tambor and Vijes show a strong ressemblance to the oceanic, cal-alkaline VAG as defined by PEARCE *et al*, (1984). They are however, relatively more enriched in Zr, Sm, Y and Yb, and in this part of their pattern they exhibit a positive slope, which is almost indentical to that shown by both the island arc tholeiitic and the "supra-subduction zone" (SSZ) granites (PEARCE *et al*, 1984). Both these letter types however have LREE depleted patterns and therefore it appears that, geochemically, a low-K, calc - alkaline, island arc granite offers the closest comparison to those of El Tambor and Vijes.

DISCUSSION

Although the age of the Vijes Felsites is nor precisely known their geochemical similarity with the El Tambor leucotonalite suggests a common origin. As discussed earlier, the bulk of the Western Cordillera sequence is post Aptian/Albian and the majority of fossil dates indicate a Turonian to Maastrichtian range (ALVAREZ, 1983). The fact that K/Ar dates of 84 ± 2 Ma. and 83 ± 3 Ma. have been obtained from El Tambor leucotonalite, would seem to indicate therefore that the granitoid is contemporaneous with the basalts of the Diabase Group. Hence any model which seeks to explain their origin must take into account not only their distinctive geochemistry but also their close association with a thick sequence of low-K tholeiites. The two most obvious possibilities would appear to be that they represent either late-stage differentiates of the basalts, or discrete magmas which were derived from the same general environment as, but independently of, the basalts.

The difficulties of producing large volumes of primary granitic melts directly from the mantle are well documented (WYLLIE *et al.*, 1976). There are however known examples of granites, which are found in association and are

TABLE 1

(1)	(1)	(2)
SiO_2	75.60	75.70
TiO_2	0.25	0.39
Al_2O_3	12.10	11.30
Fe_2O_3	3.35	4.44
MnO	0.06	0.17
MgO	0.65	0.67
CaO	2.36	1.19
Na_2O	3.96	5.56
K_2O	1.41	0.07
P_2O_5	0.07	0.08
TOTAL	99.73	99.53
Ni	2	0
Cr	0	0
V	27	4
Rb	21	2
Sr	108	26
Y	50	38
Zr	136	126
Hf	4.25	3.36
Nb	8	6
Ta	0.52	0.41
Ba	621	21
La	14.18	8.31
Ce	34.21	20.01
Nd	18.50	14.62
Sm	4.77	4.27
Eu	1.02	1.29
Gd	5.65	5.17
Tb	1.01	0.83
Tm	0.83	0.56
Yb	5.26	3.70
Lu	0.85	0.60
Th	2.14	1.08
K/Ar	670	350

(1) = El Tambor
(2) = Vijes felsite

broadly contemporaneous with oceanic, island arc basalts (GILL, 1970; ISHIZAKA an YANAGI, 1977).

The low $^{87}Sr/^{86}Sr$ ratios of the El Tambor leucotonalite (0.7038 ± 0.00008) eliminates the possibility of anything other than a mantle origin and since the corresponding ratios for the Diabase Group range from 0.7035-0.7041 ± 0.0001 (BROOK, per. comm.) this would suggest that these rocks were derived from the same source region. The Diabase Group basalts are LREE depleted and while low-pressure fractionation of these may have produced the LREE enriched Western Cordillera granitoids, using such a model it would then be difficult to explain their low immobile element values, and in particular that of Ta. The increase in Rb, Zr, Ce, Nd and, to a lesser extent Y, suggest plagioclase fractionation, and this observation is consistent with the pronounced negative Eu anomalies of El Tambor and Vijes. At the same time the parallel increase in the Ce/Ye ratio, compared to the Diabase Group basalts (see MILLWARD *et al.*, 1984), indicates a strong influence from clinopyroxene fractionation (ARTH and HANSON, 1975). Both plagioclase and (?)clinopiroxene fractionation would however tend to concentrate Ta in the residual liquid. As mentioned above, the Ta values of El Tambor and Vijes are low and it would be difficult therefore to derive these rocks directly from the basalts of the Diabase Group by a simple comagmatic differentiation scheme.

As noted earlier, with the exception of the El Tambor leocotonalite and the Vijes Felsites, the majority of the intrusives of the Diabase Group are dominantly gabbroic in composition. Based on the field evidence it is probable that these intrusives also represent an integral part of the Western Cordillera "volcanic" sequence. For the time being however, in view of the limited geochemical and, in particular, petrological data which is available from these intrusions, coupled with the lack of precise age control, in would be unwise to speculate on their role in any model concerning the origin the low-K granitoids of the Western Cordillera.

Based on the limited ammount of geochemical information, any conclusions reached concerning the origin of the El Tambor leucotonalite and the Vijes Felsites must necessarily be regarded as preliminary. With this in mind we would suggest that these rocks most closely represent those granites which are associated with low-K, juvenile, island arcs and that potentially they could be examples of single-stage, mantle-derived (M-type) granites (WHITE, 1979; PITCHER, 1983). Their coeval association with the Diabase Group lends support to the interpretation of these basalts as the base, or lower portion, of an immature island are (McCOURT and ASPDEN, 1985).

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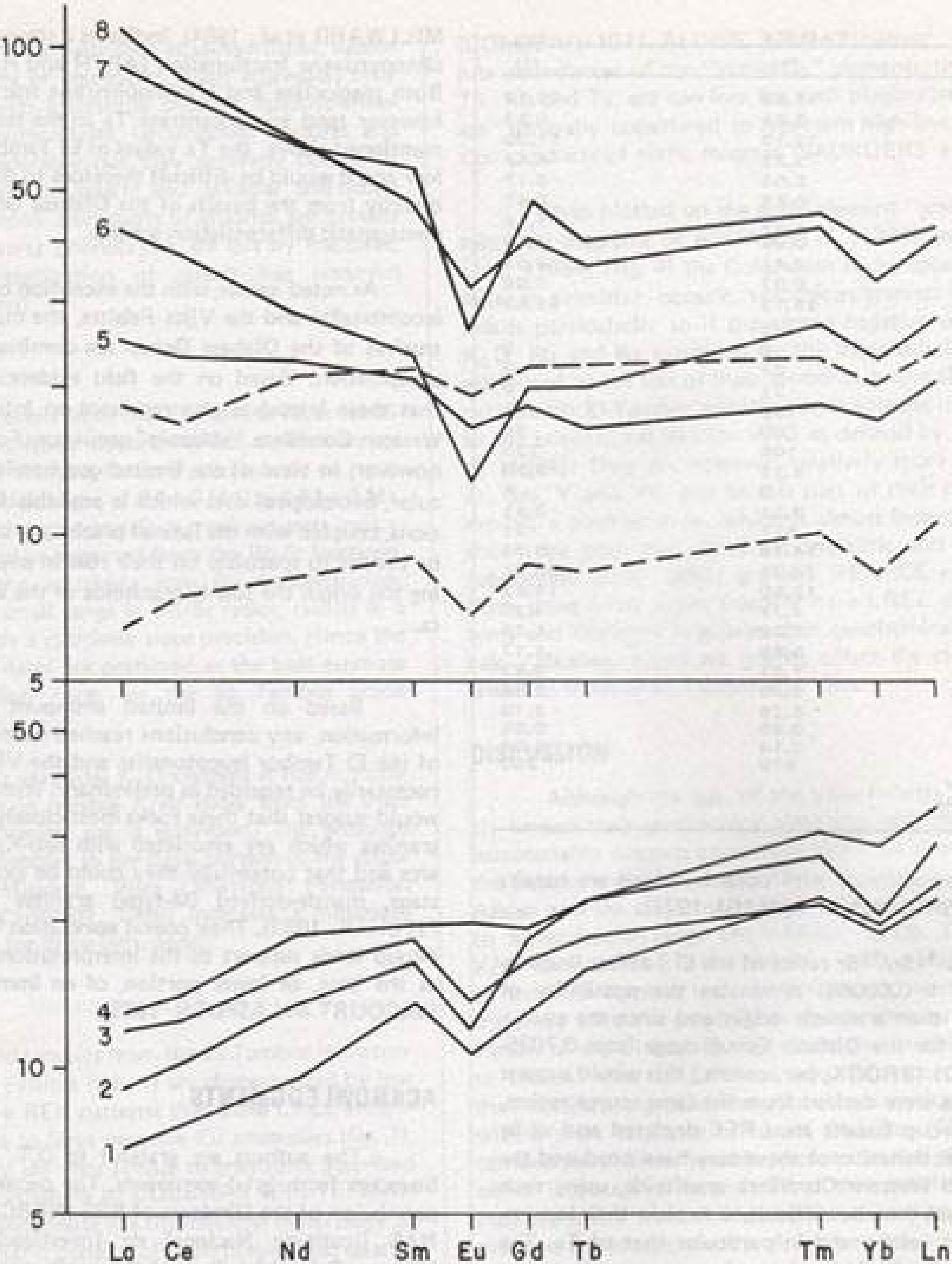

FIG. 3: Chrondrite normalized rare earth profiles for the El Tambor leucotonalite and Vijes felsite compared with ophiolitic and ocean crust plagiogranites. The broken lines define the field of Diabase Group basalts (based on 15 analyses given in ASPDEN, 1984; see also MILLWARD *et al.*, 1984) Chrondritic abundances after NAKAMURA (1974). 1, 2 = Ophiolitic plagiogranites (ALDISS, 1981; COLEMAN, 1977); 3 = Primitive island arc tholeiitic plagiogranite (ALABASTER *et al.*, 1982); 4 = Supra-subduction zone granite (SSZ) (PEARCE *et al.*, 1984; ALABASTER *et al.*, 1982); 5, 6 = Western Cordilleran low-K granitoides (Table 1, this paper); 7 = Ocean crust plagiogranite (ALDISS, 1981); 8 = Back arc basin plagiogranite (SAUNDERS *et al.*, 1979).

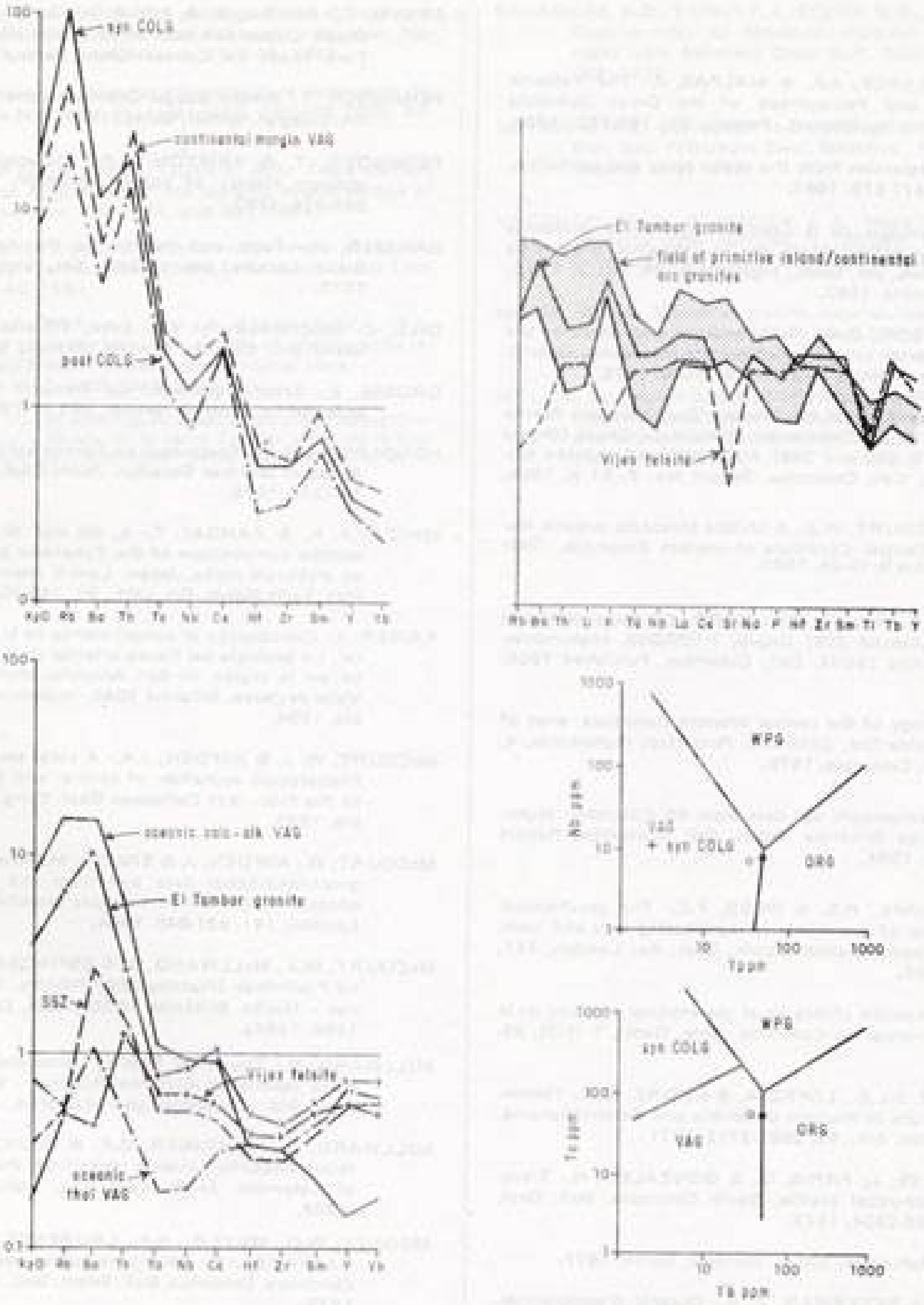

FIG. 4: Multi-element and trace element discrimination diagrams for granitic rocks (PEARCE *et al.*, 1984; BROWN *et al.*) VAG = Volcanic arc granite; ORG = Ocean ridge granite; WPG = Within plate granite; COLG = Collision granites; SSZ = Supra-subduction zone granite; open circles = Vijes felsite; closed circles = El Tambor leucotonalite.

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