

GEOCHEMICAL CHARACTERISATION OF METABASITES IN N. PORTUGAL AND SIGNIFICANCE FOR CU-FE SULPHIDES

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SUMMARY.— Polymetamorphic mafic and ultramafic rocks outcrop in thrust complexes in N.W. Iberia. The Morais and Braganca complexes in Portugal are the southernmost. Geochemical data show that the amphibolites had tholeiitic protoliths - probably ocean floor basalts. They further show a stratigraphic arrangement with cumulate and gabbroic protoliths occurring close to the ultramafics and volcanic ones further away. These data support our ophiolitic model for the complexes and emphasize their close similarity with those in Spain.

The Spanish complexes contain economic Cu-Fe sulphide ores. Field and geochemical criteria have been developed at Santiago to define amphibolites that host mineralization. These criteria show that potentially mineralized amphibolites do occur in both Portuguese complexes. An outcrop of Cu-Fe sulphides in the Morais complex is identical to one from Santiago.

Basalts in melange around the Spanish complexes are geochemically different. They contain some Cu-Fe sulphide mineralization. Similar basalts in melange around the Portuguese complexes will by analogy also be different and will not be prospective for Santiago - type mineralisation.

SUMARIO.— Rocas polimetamórficas máficas y ultramáficas afloran en los cabalgamientos del NO. de la Península Ibérica, en Portugal y España. Los complejos básicos de Morais y Bragança, en Portugal, son los más meridionales. Los datos geoquímicos indican que las anfíbolitas de los complejos portugueses eran originalmente toleitas, probablemente basaltos oceánicos, y con una disposición estratigráfica según la cual las rocas procedentes de gabros y acumulados ocurren en las proximidades de los afloramientos ultramáficos, mientras que las de origen volcánico aparecen a mayores distancias. Estos datos respaldan un modelo ofiolítico para los complejos portugueses, y ponen de relieve sus marcadas analogías con los complejos españoles.

Estos últimos contienen yacimientos de sulfuros de cobre y hierro, habiéndose establecido en Santiago los criterios geoquímicos y de campo para definir cuales son las

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anfíbolitas que encajan la mineralización. Estos criterios indican que anfíbolitas con potencial minero ocurren también en ambos complejos portugueses, ya que un afloramiento con sulfuros de cobre y hierro en el complejo de Morais tiene características idénticas a las menas de Santiago.

Los basaltos de las «mélanges» situadas alrededor de los complejos españoles son geoquímicamente diferentes, aunque contienen indicios con sulfuros de cobre y hierro sin interés económico. Por ello los basaltos similares de las «mélanges» que rodean los complejos portugueses no tienen interés para la prospección de mineralizaciones de tipo Santiago.

INTRODUCTION

BADHAM and WILLIAMS (1) proposed that the mafic-ultramafic poly-metamorphic complexes in the Hercynide core zone of NW Spain (Galicia) were relicts of Lower Paleozoic ophiolites. This interpretation was strongly based on the geochemistry of amphibolites and their contained mineral deposits and supported the similar interpretation of Bayer and Matte (2) based principally on structural and geophysical criteria. In particular Badham and Williams, and Williams (3, 4) developed a model for the genesis of cupriferous iron sulphide deposits in the amphibolite and, thence, field and lithochemical prospecting criteria.

From field, structural and petrographic study, Ribeiro (5) concluded that the two similar complexes in N. Portugal (Morais & Braganca: Fig. 1) were allochthonous and ophiolitic. This paper provides preliminary geochemical data from the Portuguese complexes to test the ophiolite model and further applies the lithochemical prospecting criteria. As a comparative exercise mafic volcanic rocks from the Cabo Ortegal melanges were also studied; they too contain cupriferous iron sulphide deposits.

The Braganca and Morais complexes were mapped by Neiva & Anthonioz (6) and described in a memoir to go with this map (5). The data therein provide the background to this study and are used with little modification, although some of the interpretations differ. In this study J.P.N.B. is responsible for field and geochemical data; D.E.W. for geochemical data and P.J.W. for petrology.

THE MORAIS COMPLEX

The Morais Complex is circular and dissected by a late, normal fault (Fig. 2). The polymetamorphic rocks lie in saucer-shaped thrust slices above a Lower Paleozoic sedimentary and volcanic sequence. The high grade rocks are commonly

flanked by greenschist metabasites that were mapped as part of the parautochthon rather than allochthon. Exposure of the contact area is poor, but in three places we observed a gradual transition in metabasites from greenschist facies with post-tectonic chlorite porphyroblasts (Ribeiro's parautochthonous greenstone) through upper greenschist facies retrogressed amphibolites (Ribeiro's allochthonous schistose amphibolite) to normal amphibolites. The porphyroblastic greenschists are retrogressed amphibolites; geochemically (see below) all three lithologies are closely similar.

In the central parts of the complex there are a few small exposures of 'blastomylonitic' * amphibolite, usually garnetiferous, and larger areas of serpentinised ultramafics. The latter often contain flaser 'gabbros' at their contacts with the amphibolites. Ribeiro (1974) noted that the amphibolites are variably retrogressed and sheared but are banded and of different grain size and mineralogy. He noted leucocratic, melanocratic, gabbroic, fine-grained and epidotic bands but did not make clear whether he considered these bands as original or metamorphic. Structurally high in the amphibolite sequence he noted bands containing garnet, staurolite, orthoamphibole and sulphides closely associated with quartz-garnet-muscovite-kyanite-plagioclase schists.

Our field and petrographic studies of the amphibolite centred on determining the nature of the banding. Amphibolites with well-developed mineralogical banding ('inhomogeneous') were identified as host to mineralisation in the Santiago area (1). In the Morais complex primary banding is evident in the rapidly and irregularly varying proportions of plagioclase and hornblende. No clinopyroxene, garnet, quartz, sulfide, or two-amphibole bands were located during the brief traverses. However, Ribeiro noted diopsidic and garnetiferous bands in places. The bands seen are on an S_1 foliation and are locally affected by D_2 high-strain zones. In these S_1 is increasingly crenulated and then obscured by the growth of new amphibole on S_2 . The new mineral banding so developed shows no relationship to the S_1 mineralogical bands. At locality 413 (Fig. 2) the S_1 bands can be seen closing on intrafolial F_1 isoclines: this supports their interpretation as primary features.

Primary bands identified include coarse and fine amphibolite (possibly a metamorphic effect); pure amphibole (altered or cumulate protoliths); pyritic amphibolite (altered or chemical sediment protolith); thick (1m) bands of massive fine amphibolite in flaser-gabbro-type amphibolite (dyke in gabbro protoliths);

* According to Spry (7), the term 'blastomylonite' should be used for rocks in which porphyroblasts have grown during and as a consequence of mylonitisation. This is the implication of the use of the term by Ribeiro (5) and Van Zuuren (8). All these rocks examined by us were seen to be cataclastic amphibolites, the porphyroblasts being relicts of a pre-cataclastic metamorphic assemblage. The term is retained in this paper with this qualification.

alternating bands with and without plagioclase porphyroblasts (variably porphyritic gabbro or lava protolith); and plagioclase-quartz-rich bands in amphibolite (leucodioritic dyke protolith). In the Peredo and 51-52 areas, greenschist metabasites have irregular and epidotic and quartz-muscovite-actinolite bands, (basaltic tuff protolith). Some of the quartz-schist areas contain thinner bands of pure fine-grained quartz (chert protolith) and at locality 52 some of these contain tourmaline. It is difficult to envisage a model for the origin of such irregular and mineralogically variable banding based entirely on metamorphic segregation.

The flazer gabbros are very variable containing thick amphibolite bands, interpreted as dykes, and also layers of pure amphibole, possibly of cumulate origin. There are thin lenses of flazer gabbro, amphibolite and plagioclase-serpentine rock (troctolitic protolith) in the main body of the ultramafic wherever it was examined. The ultramafics vary from serpentinitised lherzolite and harzburgite to pure serpentine, possibly after dunite. The amphibolites near the ultramafic often contain bands of serpentine-plagioclase rock (cumulate protolith).

In detail the ultramafic-amphibolite contact is tectonic and small lenses of serpentine also appear in the main marginal thrust. However, the general sequence from inhomogeneous metabasites through amphibolites to ultramafics can be seen as gradational in most traverses. This sequence is interpreted as being from tuffs and sediments through lavas and gabbros and into cumulates. It is a plausible sequence and is interpreted as ophiolitic within the strict terms of the Penrose definition.

The blastomylonites (locality 59 Fig. 2) lie in a separate structural slice and have a mylonitic contact with surrounding rocks. They contain garnet porphyroblasts with plagioclase coronas, amphibole and spinel. They appear to be similar to the amphibolites but having undergone a somewhat different metamorphic history.

The anomalous sulphide-bearing amphibolite (Locality 416, Figs 2 and 3) lies in epidote-banded amphibolites, themselves within more normal amphibolites. Epidote bands make up some 40% of the rock. The sulphidic lens contains large porphyroblasts of pink garnet in a quartz, fibrous orthoamphibole, staurolite, biotite, pyrite, pyrrhotite, chalcopyrite rock. This is identical to the main ore of the Arinteiro and Bama mines at Santiago (3, 9). It is structurally underlain by 2m of muscovite-pink garnet-plagioclase quartz schist grading to almost pure garnet-quartz-plagioclase rock. The upper structural contact of the sulfidic lens is clearly a late (brittle) tectonic feature: the lower contact is gradational and may be original.

The mafic and ultramafic rocks of the Morais complex are structurally overlain by the Lagoa augen gneiss and then by schists. Ribeiro (5) and Anthonioz (9) interpret the contact as an unconformity, the augen gneiss being a basal con-

glomerate and arkose sequence. The contact was examined at all localities between 415 and 416 (Fig. 2). It is clearly tectonic, with lenses of amphibolite in the gneiss near the contact and the strain increasing over 50m towards the contact from both sides. The variable grain-size of the gneiss is the result of differential granulation in the high-strain zone and the ½m wide contact itself is mylonite. The felspar augen are spatially related to the contact but pre-date the main strain: the stretching lineation on them dips 35° to the north, in agreement with the transport directions (derived from vergence) of F₂ folds (5, 9). These gneisses and schists are interpreted as felsic volcanic and plutonic rocks and derivative sediments: their relationship to the amphibolites is not clear.

The Morais amphibolites show an early (M₁) amphibolite facies assemblage often almost completely overprinted by a second similar one: the rocks are thus closely similar to those at Santiago (3). However, retrogressive metamorphism at Morais is far more intense. At Santiago the retrogressive assemblages are localised around late D₂ brittle structures, possibly related to post-emplacement uplift. It is not clear why such features should be more highly developed at Morais. There is no equivalent of the post-tectonic chlorite porphyroblasts at Santiago: they may reflect some post-emplacement parochial thermal event at Morais, perhaps a Hercynian pluton.

THE BRAGANCA COMPLEX

This complex is far more deformed and less well exposed than Morais, but the same essential features are preserved. Ribeiro (5) notes the marginal zone of amphibolitic schists passing into amphibolites and then a greater abundance of blastomylonitic amphibolite and ultramafic. Structurally above these are high-grade felsic gneisses and migmatites, with lenses of eclogite. Again, the complex is flanked by greenschist metabasites thought to be parautochthonous (5). Our studies again show continuity from these greenschists into the amphibolites: indeed, the greenschists often contain lenses of amphibolite and ultramafic and are clearly thoroughly retrogressed equivalents of these rocks.

The Braganca amphibolites are as variable as those of Morais, but, particularly in the south and east, contain spongy, brown garnets (localities 515 and 516). It is these that seem to have been mapped as blastomylonite (9). In the 520-521 area there are numerous leucocratic bands and some of these contain pyrite and chalcopyrite: these may have been interflow exhalative sediments.

The Braganca amphibolites have had a similar metamorphic history to those of Morais, but the garnetiferous rocks examined contain diopside and quartz. The garnets contain aligned inclusions of hornblende and plagioclase and are probably of late M_1 or M_2 genesis. The greenschist retrogression is not as severe as at Morais. In this and the preservation of abundant garnetiferous amphibolite, these rocks resemble even more closely those of the Santiago area.

The ultramafic rocks are also similar to those at Morais but were only briefly examined. Some of the felsic gneisses in the Braganca complex are clearly different. Quartz-felspar-garnet-muscovite rocks, often banded and migmatitic, occur to the north and east of the town of Braganca. To the west there are quartz-felspar-garnet-mica-kyanite rocks similar to the Lagoa schists at Morais, and indeed to the metasediments above the Santiago amphibolites (3, 8). Both types of gneiss develop felspar augen close to the contact with the mafic and ultramafic rocks, though not as prominently as at Morais. No exposed contacts were found for detailed examination.

THE CABO ORTEGAL MELANGE

Ribeiro (5) reports melange of mafic and felsic volcanics, cherts and argillites around the Portuguese complexes. Arps et al (10) describe similar rocks around the Ordenes Basin. In all these areas exposure is poor and it is not clear whether the rocks are true melanges (tectonised olistostromes), or just tectonically complicated volcano-sedimentary suites. Melanges around ophiolites often contain placoids of the ophiolitic rocks and it is important to recognise these. In the Portuguese and Ordenes areas we saw no evidence for olistostromes and feel that these marginal sequences do not contain equivalent strata (or fragments thereof) to those in the high-grade complexes.

Melanges around the Cabo Ortegal Complex (Fig. 1) are better exposed and are clearly tectonised olistostromes. They contain phacoids of mafic and felsic volcanics, cherts, limestones and serpentinites in a Silurian argillaceous matrix (11). The mafic volcanics contain cupriferous pyrite lenses, particularly in the Moeche area, about 20 kms south of Ortiguira (Fig. 1). The rocks here are at greenschist facies and have been folded into eastward overturned structures. They, and their tectonic fabric, dip gently beneath the amphibolites of the Cabo Ortegal Complex.

The olistostromic nature of the sequence is clearly displayed on the Playa de Espasante section near Ortiguira. Lenses of tuff and porphyritic basalt, some with intense epidotic alteration and others containing mafic dykes, are contained

in a micaceous phyllite matrix. Several phacoids themselves consist of earlier breccias of lava in phyllite. The whole sequence has been tectonised and metamorphosed to upper greenschist facies. It was thought that some of the basaltic clasts could have been shed into the melange from the ophiolite sheets during their emplacement, and that they could, therefore, be equivalents at lower grade, of the amphibolites. Further, it was thought that the sulfide bodies could be equivalent to those in the amphibolites.

Petrographic study of the basaltic rocks shows them to be chlorite-albite-epidote assemblages. At such grades subtle chemical variations (hydrothermal alteration, interflow exhalative sediment) may not find a ready mineralogical expression, being 'hidden' in chlorite. However, in the mineralised area pure chlorite lamellae interbedded with sulphides, greater development of epidote and local quartz suggest exhalative and hydrothermally altered precursors respectively. Three samples of massive lava and dyke were taken the Espasante melange for geochemical comparison with the amphibolites.

At the north end of the Playa, around the harbour, phacoids of highly strained pillow lava and tuffaceous melange abut amphibolites of the Cabo Ortegual complex. In the 20 m towards the contact the strain increases rapidly and the melange becomes an epidote-amphibolite schist with phyllonitic bands in which quartz and sometimes felspar porphyroblasts have grown. Remarkably similar rocks (the Landwednack schists) and some of the Kennack gneiss) occur at the base of another Hercynian ophiolite, the Lizard Complex in Cornwall (12). An origin as metamorphosed and highly strained melange was postulated for these (13).

GEOCHEMISTRY

55 samples from Morais & Braganca and 3 from near Ortiguira were analysed for major and trace elements. All the samples were fresh and weathering effects (3) can be ignored. The results are reported in Tables 1 & 2.

The first conclusion is that the chlorite porphyroblastic greenschists, the epidote amphibolites, the amphibolites and the blastomylonitic amphibolites are closely similar in composition and probably had a similar protolith. Leaving out the two ultramafic rocks and the various 'abnormal' rocks the whole population can be treated in the same manner. The second, and equally clear conclusion is that the Ortiguira basalts are not part of this population. They are nevertheless basaltic and are examined on the same discriminant diagrams as the amphibolites (Figs. 4 - 6).

In view of the rather variable metamorphic grades in the rocks, particularly in the development of epidote, it is important to examine any possible metasomatic changes resulting from this variation. To this end two groups of samples were collected with epidotic, retrogressed and non-epidotic rocks in close proximity. 43A (amphibolite) and 43B (epidote amphibolite) differ only in that 43A has higher SiO_2 . Al_2O_3 , K_2O , Ni and Cr are also slightly higher but are within one standard deviation of the amphibolite 'norm' (table 2) so the difference is not regarded as significant.

At the mineralised horizon (416) the strongly epidotised samples (C and G) are slightly enriched in CaO, Ti, Y and Zr and depleted in MgO, Na_2O , Mn and Zn, compared with the 'normal' amphibolites there (A and B) or the amphibolite norm. It is argued below that these changes are the result of pre-metamorphic alteration: none of these samples is used in a discriminatory role. It is concluded in general that the effects of post-metamorphic retrogression are of little chemical significance.

The linear relationship of all the samples on the Fe_2O_3 : MgO plot (Fig 4A) probably indicates varying degrees of differentiation in the protolith. This is insufficient to preclude the use of major element discrimination plots (Figs. 5A & B) which identify all the rocks as sub-alkaline and tholeiitic. The A F M diagram more clearly illustrates the range of differentiation on a classic tholeiitic trend and particularly shows the differentiated nature of the Ortiguira basalts. These plots identify two separate suites of amphibolites whose differences may be a consequence of differentiation:

- a) S Morais suite plus some from W Morais and Braganca
- b) N Morais suite and remainder from W Morais and Braganca.

Samples not part of one of these suites are considered geochemically anomalous. They include 56B, an amphibolite band within ultramafic (56A). The high MgO suggests an olivine gabbro or cumulate origin. The high Ni and Cr and low Ti, V, Zr and Y suggest an origin as a cumulate within the ultramafic. Samples 413A, B and C, were collected to note possible variation in differentiation between amphibole and leucocratic bands; they are not used in the discrimination diagrams. None of the other samples for which some mineralogical variation was noted show any chemically anomalous behaviour (eg 45A - quartzose; 49 A - pyritic; 414A - leucocratic). Of the pure amphibole bands, 413A has low Al_2O_3 and Y, and high MgO, Cr and Ni, and is possibly a cumulate. 517B has low Si and high CaO and volatiles it is actinolitic and is probably severely retrogressed.

In the light of these conclusions, it is proposed that the stable trace elements can be used to discriminate the tectonic environment of generation of these tholeiitic rocks (3, 4, 14, 15, 16, 17). The reservations of Prestvik (18) particularly concerning the effects or differentiation of basalt on these discriminant dia-

grams are noted. By studying the degree of differentiation and not using differentiated or cumulate samples in the discrimination we feel that the plots are valid. The Ti-Zr-Y plot (Fig. 5A) identifies the amphibolites as ocean-floor or primitive arc (Low K) tholeiites. The same is true for the Ti-Zr-Sr plots (Fig. 5B) but there is more scatter probably reflecting minor Sr mobility. The Ti-Zr plot (Fig. 6A) demonstrates the degree of differentiation particularly in the Ti enrichment. The least differentiated rocks plot more clearly in the OFB field on Figures 5A and B, but still it is not possible to discriminate between OFB and LKT protoliths. What is clear, however, is that these rocks were not within-plate basalts, but that they resemble those from the Spanish complexes (see also Table 2).

The Ti-Cr plot (Fig. 5C) again shows the effects of differentiation but identifies all the amphibolites as OFB rather than LKT. It is possible that this clear discrimination results from a higher than normal Cr content of cumulate-origin. However, the Ni-Zr (Fig. 6B) and MgO: Fe₂O₃ (Fig. 4A) plots generally preclude this. Some of the South Morais samples may have contained olivine: the Fe₂O₃/MgO plot suggests olivine as a component (19). The amphibolites are, therefore, identified geochemically as ocean-floor basalts in support of their postulated ophiolitic origin.

The Ortiguira basalts are different and could be Low K tholeiites. Their degree of differentiation precludes any firmer conclusion, but these rocks are clearly not the direct equivalents of the amphibolites.

DISCUSSION OF THE GEOCHEMISTRY

The variation in degree of differentiation over relatively wide areas suggests that these areas had different protoliths. The most differentiated Morais samples are those from the northern area. Those from the western traverse are least differentiated near the outer margin of the complex, most differentiated towards the ultramafic and contain rocks with a cumulative input near the ultramafic. Decreasing degree of differentiation away from the ultramafics is a common feature of ophiolites (20) and of modern oceanic crust (21). In both environments volcanic rocks and dykes typically retain the most primitive compositions while it is in the gabbroic magma chambers beneath this carapace that both differentiates and cumulates occur. The Portuguese results are, therefore, compatible with an ophiolite model and, taken with the field data permit the following suggestions:

- a) The north and inner western Morais amphibolites were largely gabbros
- b) The south and outer western Morais amphibolites were mostly lavas and/or dykes

- c) Much of the Braganca amphibolite was gabbroic but there are areas that were volcanic.

It is well appreciated that these conclusions are speculative and that other explanations may be possible. However, it is interesting that the mineralised area (416) is within rocks identified as volcanic rather than plutonic - exactly what should be the case if the mineralisation were volcanogenic. Furthermore, copper-rich and cherty-sulfidic rocks occur in little differentiated rocks (521 area) in the Braganca complex. No Cu mineralisation has been found in areas of more differentiated or cumulative origin. All the observations are, therefore, sensible and consistent with an ophiolite model.

GEOCHEMISTRY OF THE MINERALIZED AREA

The geology of the 416 area (Fig. 2) suggests that metasediments, epidotic amphibolites and the sulfide horizon are interbedded. These epidotic amphibolites have abnormal trace element contents compared with other amphibolites, including epidotic ones, throughout the area (Table 1). This, plus evidence for the lack of mobility of Ti, Zr, Y, V and Cr during metamorphism, suggests that the variations are the result of a pre-metamorphic process.

The sulfide-rich lens itself (416D) is mineralogically distinct. It is also geochemically distinct in being enriched in Fe, Cu, Zn, Si, Mn, volatiles, and, obviously, S, and depleted in Al, Mg, Ca, Na, Ni, Cr and Sr. The high volatile content is mainly the result of the susceptibility of the orthoamphiboles to retrogression to more hydrous phases. This mineralogy and geochemistry characterises the ore-zone at the Arinteiro and Bama mines, Santiago. There, too, the ore is enveloped by amphibolite interpreted as having had a hydrothermally altered protolith, all in an isoclinal fold nose within metasediments. The close proximity of sulfides and sediments at Morais and the quartz garnet rich nature of these sediments might suggest that the sediments contain an exhalative input. However, geochemically the rocks (416 E & F) are siliceous pelites, having low Mn and high Zr, suggesting a clastic rather than exhalative origin.

The structural relationships of the Pont d'Azibo (416) mineralisation are complex and it is impossible to tell way up, whether or not there is a tight fold, and whether the contacts are original or tectonic. It is not possible to use the proximity of sediment and sulfide horizon to predicate an exhalative origin for the mineralisation. However, the similarity of the mineralisation to that in the Santiago area suggests a similar origin. Williams (3) argues convincingly that the chemical evidence requires an origin by alteration of basalt probably in a near-surface, venting hydrothermal system.

GUIDES TO PROSPECTING IN THE PORTUGUESE COMPLEXES

Badham and Williams (1), and Williams (3), suggested an orderly approach to ground selection in the Spanish amphibolites, based on the ophiolite model. Identification of areas of amphibolite without ultramafics and then of inhomogeneous amphibolites with thin bands which may have had altered or exhalative protoliths, were noted as the principal geological criteria. On that basis, much of the Morais and parts of the Braganca amphibolites are prospective, and traditional exploration methods might sensibly be used therein. Litho-geochemical criteria can further constrain the prospective ground firstly by segregating areas with undifferentiated or non-cumulate protoliths and secondly by noting horizons of alteration or metal enrichment within these. The reconnaissance traverses reported here have identified the south and western-most Morais and parts of western Braganca areas as most prospective.

Williams (3) developed a geochemical scoring system to select areas in the Santiago amphibolites which had undergone hydrothermal alteration and possible mineralisation. This is based on the addition of Mn, Cu and Zn and loss of Sr as the most consistent and reliable combination for unweathered rocks. This factor (Table 3) has a maximum score of 18: in the Santiago area, in ground selected on the criteria above, values in excess of 10 can be considered significant, especially where they occur in groups. In the Portuguese complexes the greater range of differentiation has led to higher Mn contents. Values in excess of 12 are considered anomalous here, although it is recognised that more data and a more sophisticated approach are needed in this area.

On this basis the southern and western-most Morais area and parts of Braganca are selected as favourable. It is at first surprising that in the Pont d'Azbio mineralised area, only the mineralised sample itself is anomalous; the flanking epidotic rocks are not. This suggests that the mineralised lens may not be in its original position, but may have been tectonically relocated. Alternatively, the mineralisation may be overlain by post-sulphide volcanics (cf discussion in Williams (3) concerning a similar problem at Santiago). Either way this observation should be taken as a positive encouragement to prospect for a larger mineralised area nearby.

As a final note on mineralisation, the Spanish and Portuguese complexes were prospected for nickel sulphide mineralisation in the ultramafics. This was done at a time when the complexes were thought to be large intrusions of Sudbury or Stillwater type. No significant nickel was found. The ultramafic roots of ophiolite complexes occasionally contain small chromite lenses but never any significant nickel sulfide masses. Had the ophiolite model been generated earlier it is unlikely that prospecting for nickel would have taken place.

CONCLUSIONS

Ribeiro (5) identified the Morais and Braganca complexes as allochthonous and similar to Spanish ones, for which Badham and Williams (1) developed an ophiolitic model. Using principally geochemical criteria the similarity of Spanish and Portuguese complexes is clear and an ophiolitic model is justified for the Portuguese ones. Ribeiro's postulate is, therefore, supported. However, some of the rocks identified by Ribeiro as lying outside the allochthonous amphibolite sheets are geochemically identical to the amphibolites. It is, therefore, suggested that they are an integral part of the allochthonous complexes.

Geochemical criteria also identify the possible protoliths of the amphibolites and further select the volcanic areas as potential hosts for volcanogenic stock-work and exhalative Cu-Fe sulphide mineralisation.

Basalts from the melange of the Cabo Ortegal complex are different from the amphibolite precursors and are presumably not, therefore, spalled-off fragments of the allochthon. The Cu-Fe sulphide deposits in these basalts are volcanogenic but again cannot be directly compared with those in the amphibolites. Basalts in the autochthons beneath the Portuguese complexes appear to be in situ and not in melange.

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REFERENCES

1. BADHAM, J.P.N. and WILLIAMS, P.J. Genetic and Exploration Models for Sulfide Ores in Metaophiolites, Northwest Spain. *Econ. Geol.* v. 76, p. 2118-27, 1981.
2. BAYER, R. and MATTE, P. Is the Mafic/Ultramafic Massif of Cabo-Ortegal a Nappe emplaced during a Variscan Obduction? - A New Gravity Interpretation. *Tectonophysics* 57, T9 - 518, 1979.
3. WILLIAMS, P.J. Petrogenesis, Metallogensis and Lithogeochemical Prospecting of Metabasic Rocks near Santiago de Compostela, N.W. Spain. Ph. D. Thesis. Univ. Southampton (Unpubl) p.p. 363, 1982.
4. WILLIAMS, P.J. The Genesis and Metamorphism of the Arinteiro-Bama Cu Deposits Santiago de Compostela, N.W. Spain. *Econ. Geol.* In Subm.
5. RIBEIRO, A. Contribution à l'étude de Tras-os-Montes oriental. *Mem. Serv. Geol. Portugal*, 24, 1974, 168 p.p.
6. NEIVA J.T. and ANTHONIOZ, P.M. Carte Géologique Schematique: Tras-os-Montes. (Coordinated by A. Ribeiro). *Serv. Geol. Portugal*, 1974.
7. SPRY, A. *Metamorphic Textures*. Pergammon Press, 350 p.p. 1969.
8. VAN ZUUREN, A. Structural Petrology of an area near Santiago de Compostela (N.W. Spain) *Leidse. Geol. Med.* 45 1-71, 1969.
9. ANTHONIOZ, P.M. Les Complexes Polymetamorphiques Precambriens de Morais et de Braganca (N du Portugal). Session 1971 de l'Association pour l'Etude Géologique des zones profondes de l'écorce terrestre dans le N.W. de la Péninsule Iberique. *Livret-Guide de L'Excursion B*.
10. ARPS, C.E.S. VAN CALSTEREN, P.W.C. HILGEN, J.D. KUIJPER, R.P. & DEN TEX, E. Mafic and related complexes in Galicia: An excursion guide. *Leidse. Geol. Med.* 51, 63-94, 1977.
11. VAN DER MEER MOHR, C.G. The Palaeozoic Strata near Moeche in Galicia, N.W. Spain. *Leidse. Geol. Med.* 49, 487-97, 1975.
12. BADHAM, J.P.N. and KIRBY, G.A. Ophiolites and the Generation of Ocean Crust: Data from the Lizard Complex, Cornwall. *Bull. Geol. Soc. France.* 7.4. 885-888, 1976.
13. BADHAM, J.P.N. An Update on the Lizard. *Trans. Inst. Min. Met.* v 91, B 94-95, 1982.
14. PEARCE, J.A. and CANN, J. Tectonic setting of basic rocks determined using trace element analysis. *Eath Plan. Sci. Lett.* 19. 290-300, 1973.
15. PEARCE, J.A. Basalt Geochemistry used to investigate past tectonic environments on Cyprus. *Tectonophysics* 25, 41-67, 1975.

16. PEARCE, J.A. and NORRY, M.J. Petrogenetic implications of Ti, Zr, Yb, Nb variations in volcanic rocks. *Cont. Min & Pet.* 69, 33-67, 1979.
17. FLOYD, P.A. and WINCHESTER, J.A. Magma type and Tectonic setting discrimination using immobile elements. *Earth. Plan. Sci. Letts.* 27, 211-8, 1975.
18. PRESTVIK, T. Basic volcanic rocks and tectonic setting. A discussion of the Zr-Ti-Y discrimination diagram and its suitability for classification purposes. *Littros.* v 15, p. 241-247, 1982.
19. SUN, S-S, NESBITT, R.W. and SHARASKIN, A. Ya. Geochemical characteristics of midocean ridge basalts. *Earth. Plan. Sci. Letts* v 44, p. 119-138, 1979.
20. MALPAS, J. and STEVENS, R.K. The origin and emplacement of the ophiolite suite with examples from Western Newfoundland. *Ophiolites of the Canadian Appalachians and Soviet Urals.* Eds. Malpas, J. & Talkington RW. *Mem. Univ. Newf. Report* ≠ ≠ 8, p. 21-41, 1979.
21. THOMPSON, C. Trace element distribution in fractionated oceanic rocks; Gabbros and related rocks. *Chem. Geol.* v 12, p. 99-111, 1973.
22. IRVINE, T.N. and BARAGAR, W.R.A. A Guide to the Common Volcanic Rocks. *Can. J. Earth. Sci.* 8, pp. 523-548, 1971.

TABLE 1 (Cont.)

A	AA	PA	LA	A	SH	SH	SH	SH	SH	SH	SH	SH	A	RA
411	413A	413B	413C	414A	416A	416B	416C	416D	416E	416F	416G	417	51A	
SM	SM	SM	SM	SM	SM	WM								
0*	Δ	Δ	Δ	0*	X*	X*	X*	X	—	—	X*	0*	□*	
47.9	48.7	52.1	55.0	49.3	46.9	48.9	47.9	54.6	60.3	66.0	47.2	47.1	54.1	
0.9	0.7	1.8	1.3	0.5	0.7	1.0	1.4	1.2	0.9	0.8	1.4	0.8	1.4	
14.6	10.8	19.0	19.0	14.5	15.8	14.1	14.0	11.4	18.5	16.1	14.1	14.4	13.0	
10.0	11.3	8.9	3.8	7.8	9.4	10.2	10.0	21.0	7.5	6.4	10.6	9.2	10.6	
8.5	13.2	5.6	3.0	10.2	8.2	8.5	6.7	4.6	3.2	2.9	6.5	9.7	6.9	
11.7	10.8	8.5	7.5	11.7	9.9	11.2	15.7	—	0.9	2.1	15.6	11.9	8.6	
2.6	1.4	3.7	5.5	2.6	3.2	2.7	2.2	0.5	0.8	2.2	2.2	2.3	3.0	
—	—	—	0.1	—	0.3	0.6	0.1	—	5.1	2.6	0.1	—	0.1	
0.04	0.06	0.39	0.17	0.02	0.09	0.09	0.10	0.09	0.02	0.17	0.12	0.06	0.15	
2.1	3.1	2.8	3.2	2.4	2.3	2.4	2.0	7.6	4.3	3.2	2.5	2.2	2.6	
98.34	98.69	99.49	98.57	99.02	96.79	99.69	100.10	100.99	101.71	102.47	100.32	97.66	100.45	
—	22	20	13	—	7	11	—	—	151	66	—	—	—	
137	13	270	343	130	257	159	204	—	33	97	159	149	101	
20	55	206	113	18	28	36	53	44	154	165	49	30	94	
24	8	31	59	13	18	15	23	20	27	29	27	19	30	
—	—	—	—	—	—	—	—	—	8	9	—	—	—	
223	175	280	151	169	221	231	256	229	128	116	276	179	311	
466	1335	77	417	379	399	506	419	182	94	93	378	714	330	
1318	1496	724	223	1026	1435	1217	1264	1628	557	599	1266	1030	1662	
115	820	36	48	159	117	170	90	92	44	48	104	246	55	
37	114	183	9	—	12	42	43	1596	73	569	80	—	49	
71	44	23	10	23	105	84	62	215	74	120	75	21	106	
—	—	—	6	—	6	—	—	4	—	6	4	—	—	
—	6	5	—	—	9	5	6	—	25	18	8	—	—	
6	—	—	—	—	—	—	—	—	—	—	14	—	—	

TABLE 2

%	1	2	3	4	5	6	7
Si O ₂	48.47	50.16	1.79	48.83	55.1	47.8	51.5
Ti O ₂	1.08	1.12	0.27	1.71	1.6	1.2	2.5
Al ₂ O ₃	14.63	15.14	0.90	15.06	14.6	17.8	14.6
Σ Fe ₂ O ₃	10.03	10.38	1.04	12.44	10.8	11.5	15.9
MgO	8.25	8.54	1.50	7.02	4.8	5.6	4.1
CaO	11.21	11.60	1.69	11.89	6.7	7.0	4.7
Na ₂ O	2.75	2.85	0.39	2.64	2.5	2.4	1.2
K ₂ O	0.08	0.08	0.14	0.23	—	0.4	0.1
P ₂ O ₅	0.13	0.13	0.12	0.16	0.29	0.17	0.67
<i>L.O.I.</i>	2.43	0.00			4.1	5.0	4.9
p.p.m.							
Rb	3		5.2		—	8	13
Sr	173		55.1	131	216	288	159
Zr	53		28.9	91	175	96	167
Y	20		6.6	37	35	28	58
Nb	5			5	—	—	—
V	237		42.3	317	227	239	221
Cr	459		189.9	308	55	72	13
Mn	1277		291.1	1465	1562	2225	2317
Ni	165		111.5	95	35	31	20
Cu	48		49.4	50	85	53	183
Zn	73		28.3	94	82	103	103

Comparisons of Portuguese and Spanish Amphibolites and the Ortiguira volcanics. 1 = mean of 27 'best' amphibolites from Morais & Braganca. 2 = ditto, recalculated anhydrous. 3 = standard deviation of mean of 2. 4 = mean of Santiago amphibolites, calculated anhydrous (from Williams (3)), 5, 6, 7 = Ortiguira volcanics.

TABLE 3

Sample	Factor Score	Comment
49A	14	Prospective area (P.A.)
416D	16	Mineralised sample
51A	15	P.A.
51B	13	P.A.
59A	15	«Blastomylonite», P.A.
515	13	P.A.
517A	13	P.A.
519	13	P.A.

Factor scores for Morais & Braganca amphibolites, after Williams (3). Only samples with F 12 are presented. $F = 2 f Mn + 2 f Sr + f Cu + f Zn$.

where $fMn = 3$ for $Mn \mu+6$: $fSr = 3$ for $Sr \mu+6$
 $= 2$ for $\theta Mn \mu+6$ $= 2$ for $\mu-6 Sr \mu$
 $= 1$ for $\mu-6 Mn \mu$ $= 1$ for $\mu Sr \mu+6$
 $= 0$ for $Mn \mu+6$ $= 0$ for $Sr \mu+6$

$fCu (+Zn) = 3$ for $Cu \mu+26$
 $= 2$ for $\mu+26 Cu \mu+6$
 $= 1$ for $\mu+(Cu \mu$
 $= 0$ for $Cu \mu$.

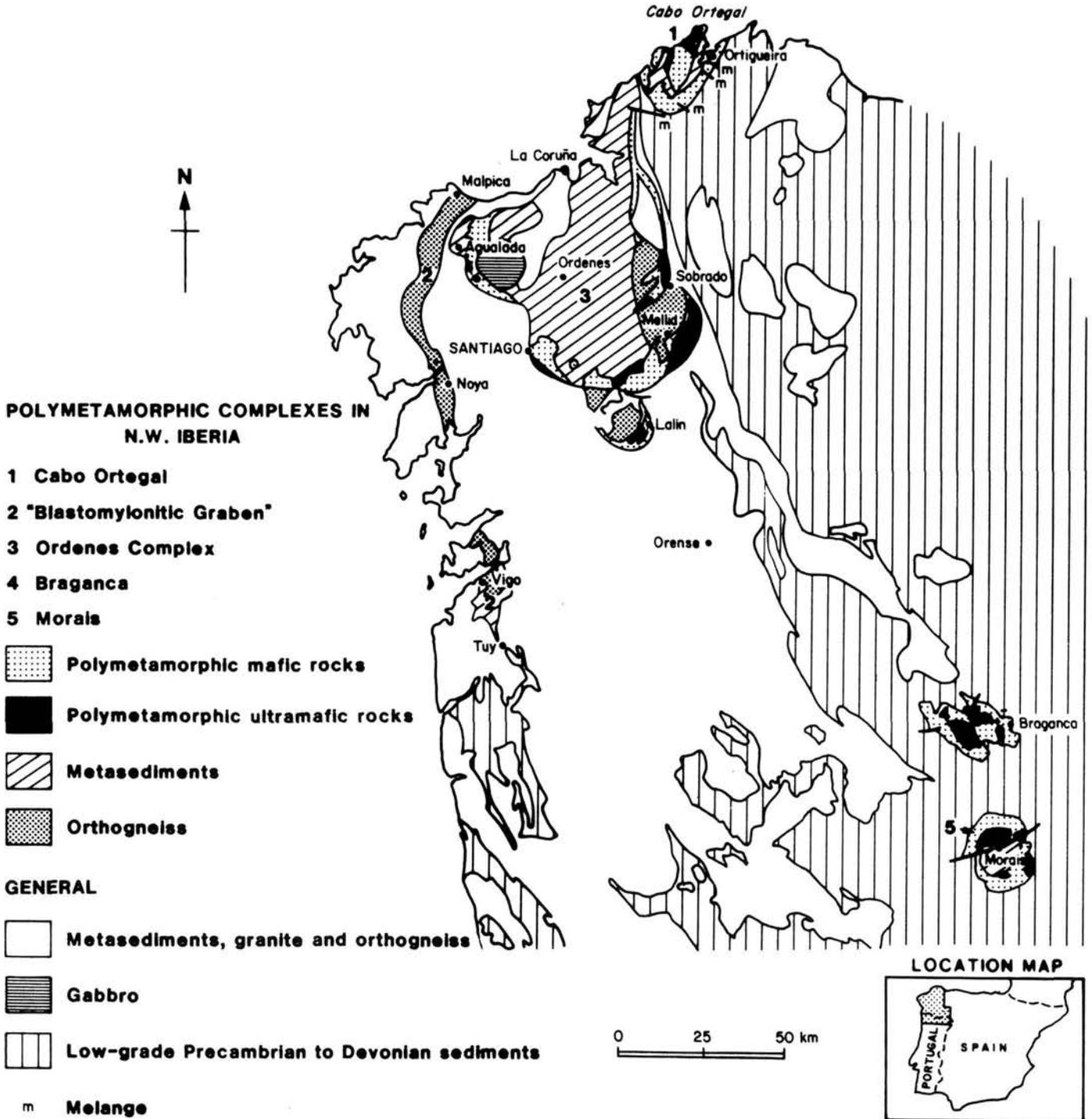


Fig. 1: Geologic map of the N.W. Iberian Peninsula showing the polymetamorphic complexes.

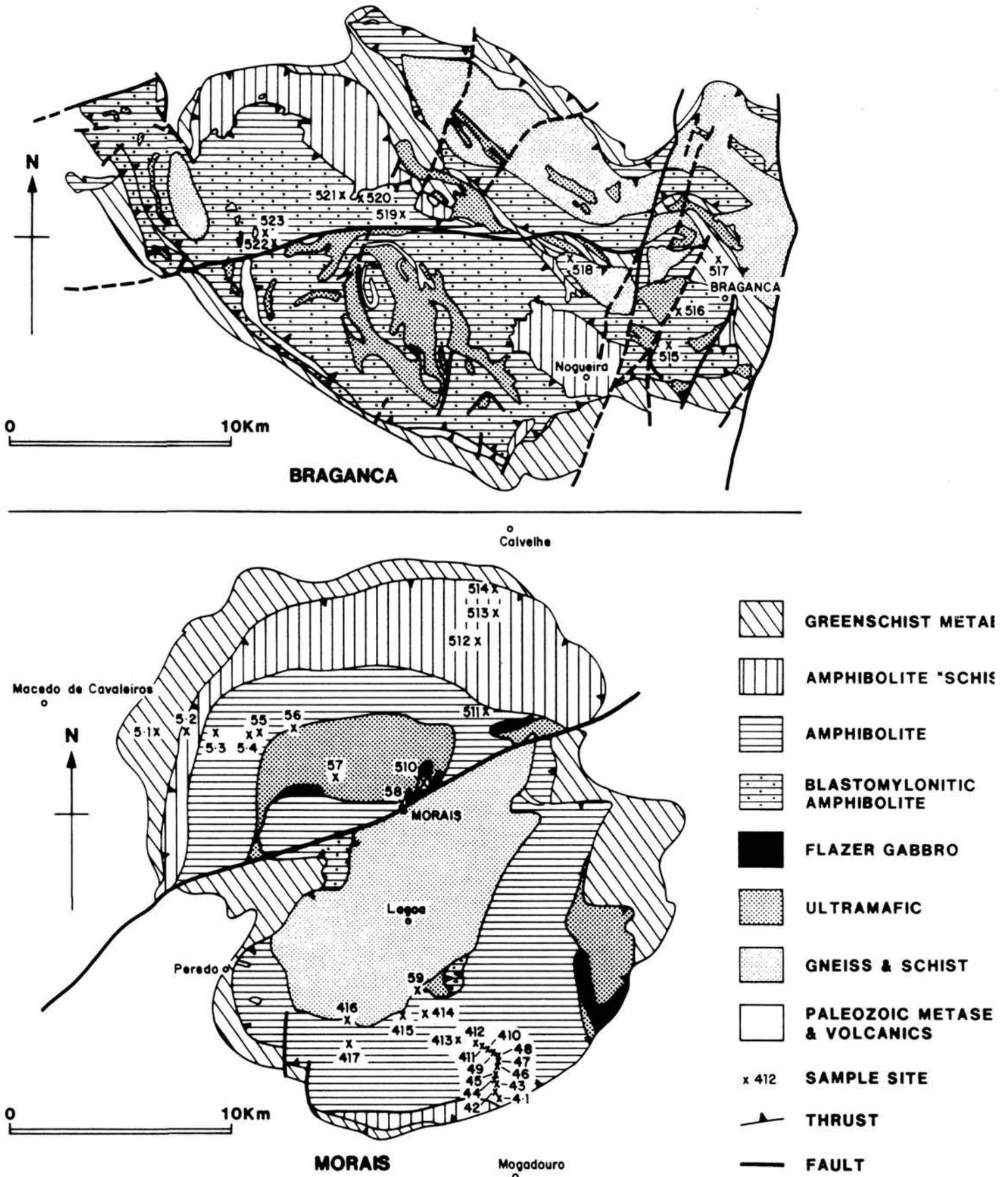


Fig. 2: Geologic maps of the Morais & Braganca complexes, slightly modified after Carte Géologique Schematique de Tras os Montes of the Servicos Geologicos de Portugal (6). Sample localities marked.

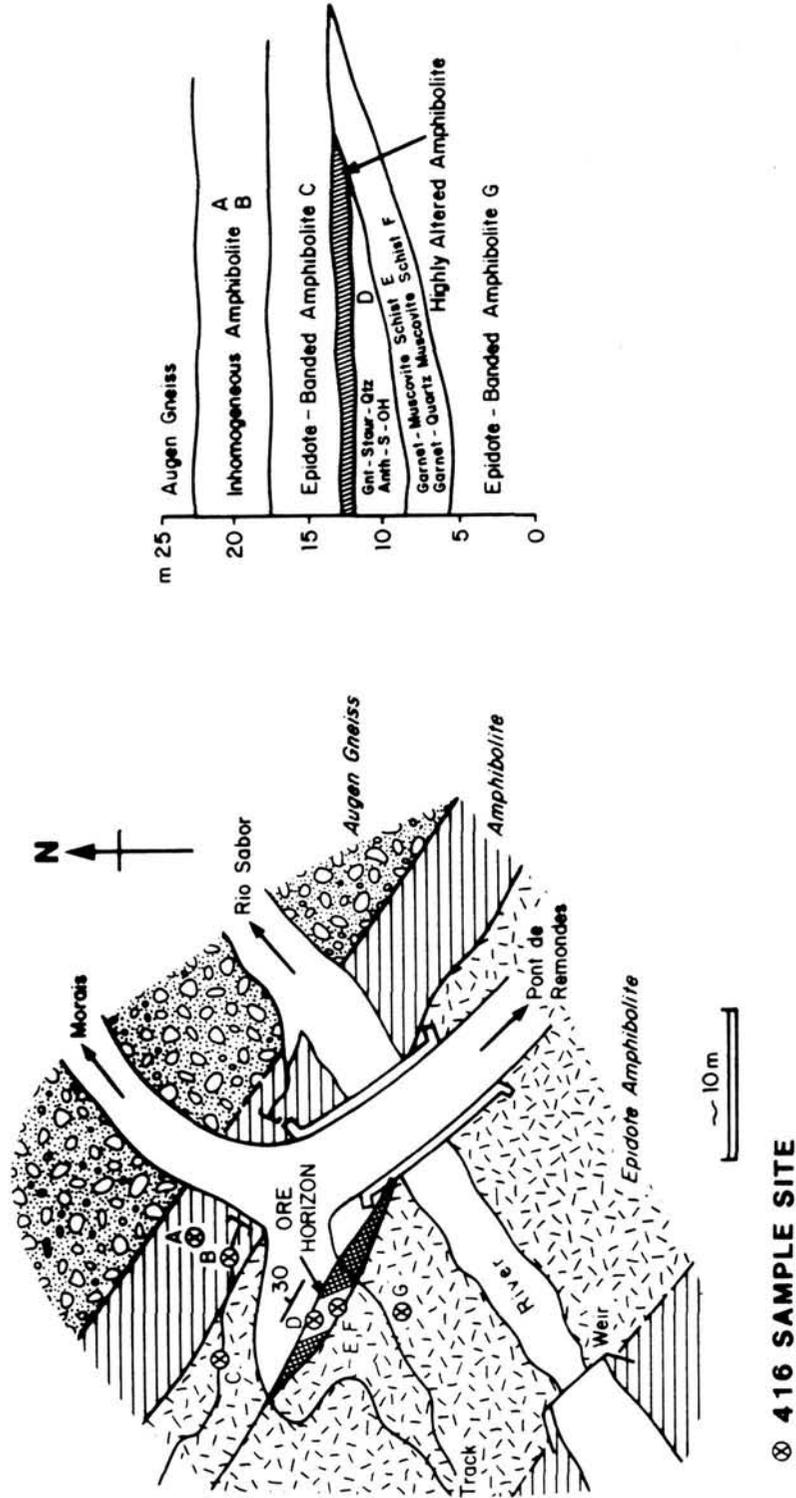


Fig. 3: Sketch map and section of the mineralisation at Pont d'Azibo (locality 416) showing sample localities.

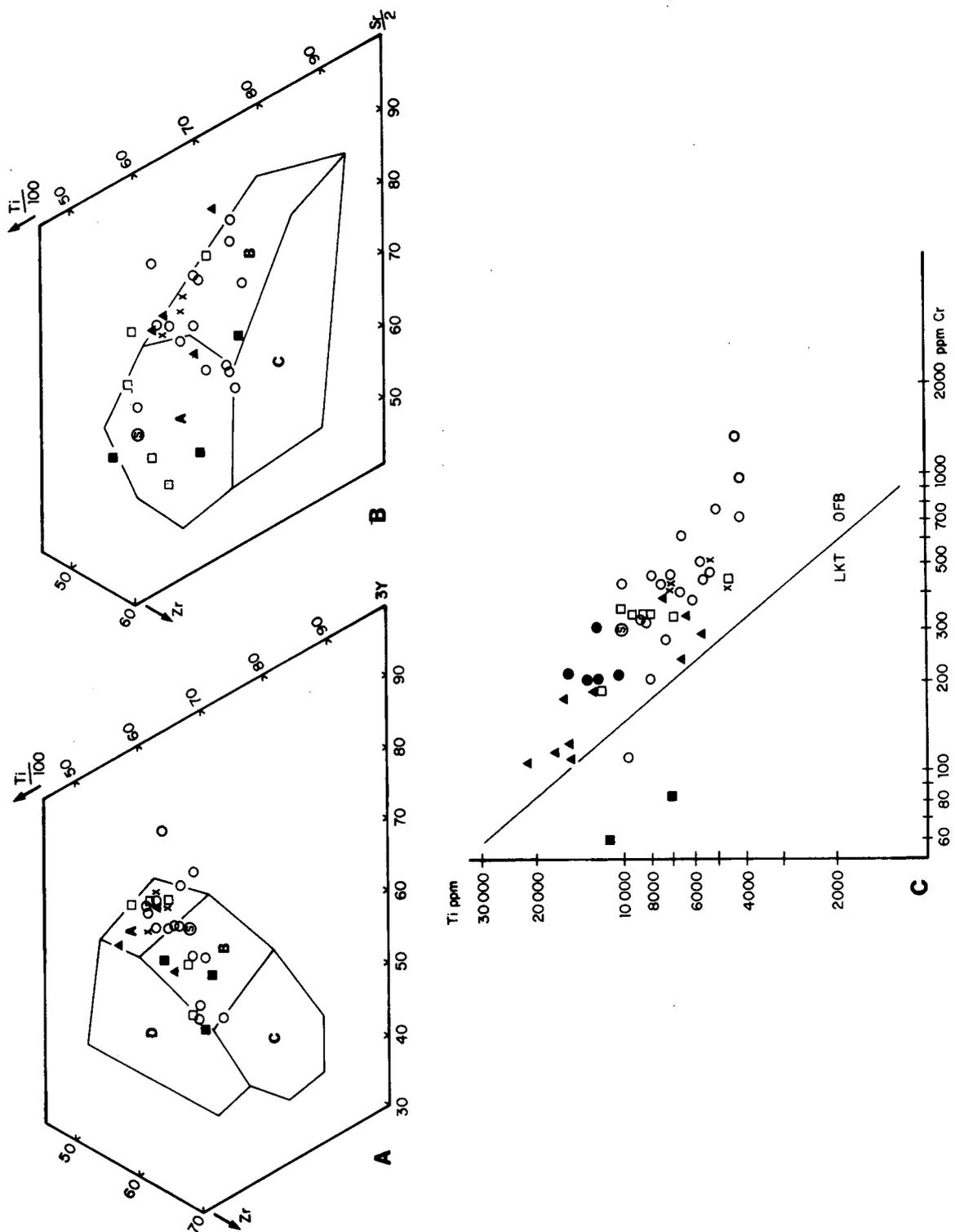


Fig. 4: A. $\Sigma\text{Fe}_2\text{O}_3$: MgO plot to show range of differentiation in the amphibolites but possible cognesis of the suite.
 B. Alkalis: silica diagram identifying the amphibolites as subalkaline (after Irving & Barager (22)).
 C. AFM diagram identifying the amphibolites as tholeiitic and showing the differentiation trend (after Irving & Barager (22)).

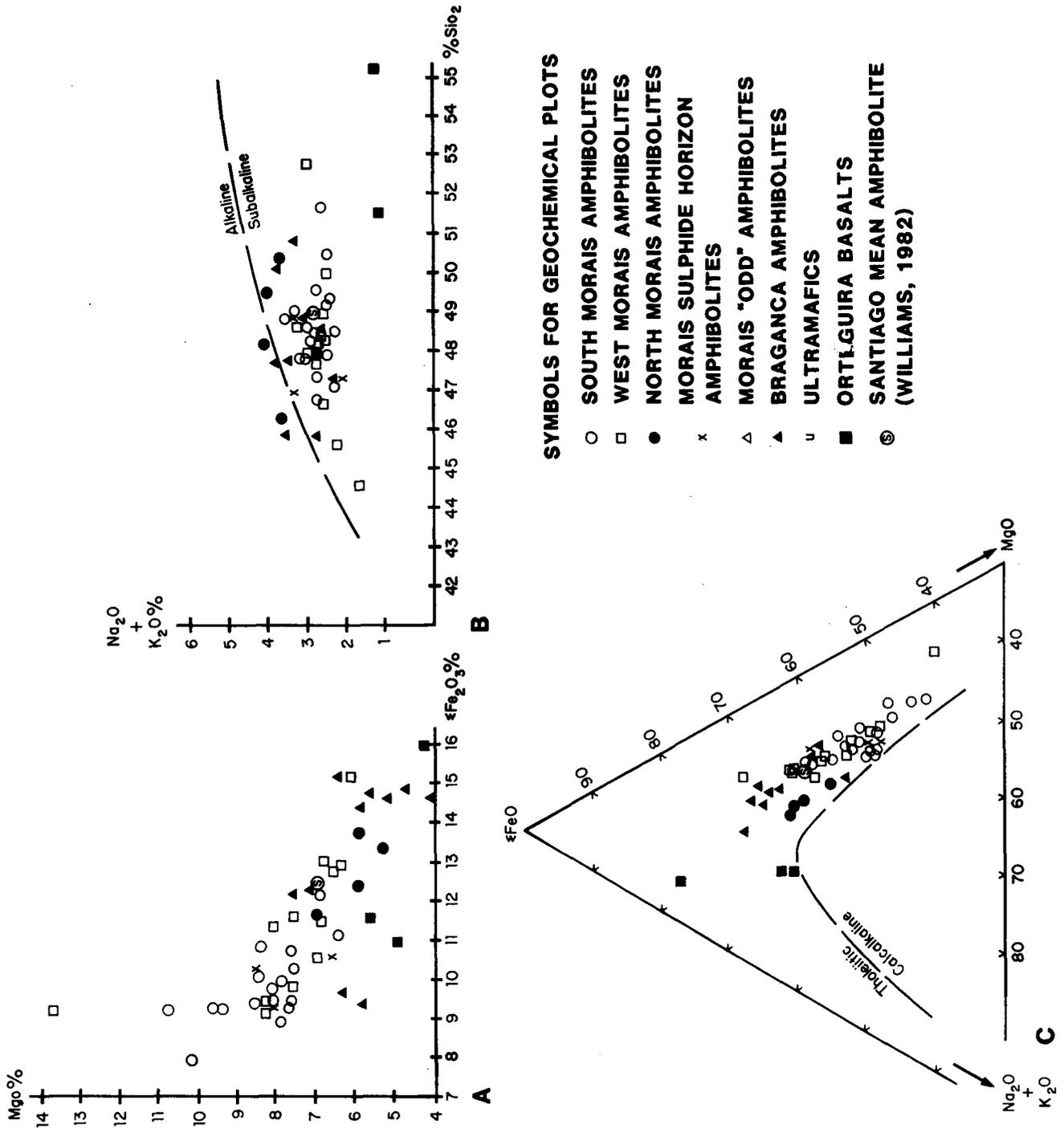


Fig. 5: Trace element discrimination diagrams for basaltic rocks (after refs. 14, 14,16) -
 A. Fields: A & B = Low k tholeiite. B. Ocean Floor basalt. B & C = Calcalkaline basalt. D = Within-plate basalt.
 B. Fields: A = Ocean floor basalt. B = Low k tholeiite. C = Calcalkaline basalt.
 C. OFB = Ocean floor basalt. LKT = Low k tholeiite.

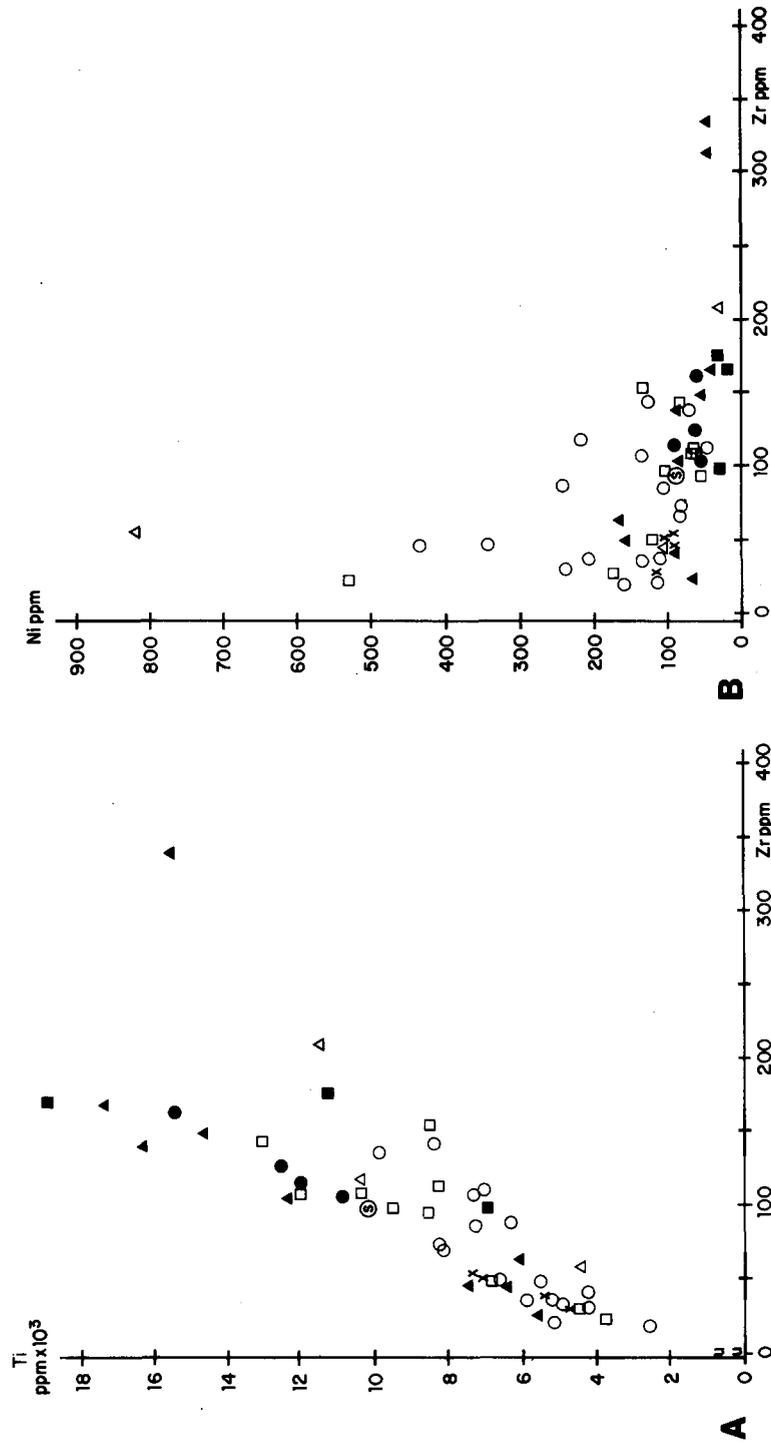


Fig. 6: A. Ti:Zr plot to emphasise the range of differentiation and identify the least differentiated samples for calculation of the mean 'best' amphibolite of Table 2.
 B. Ni:Zr plot to emphasise the regular relationship for amphibolites, indicating differentiation. High Ni samples are probably cumulates and have been excluded from the discriminant plots of figure 5.