THE GEOCHEMISTRY OF HIGH-PRESSURE GNEISSES FROM CABO ORTEGAL (NW SPAIN): RESIDUES OF DEEP ANATEXIS[1]

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ABSTRACT

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Garnet-hornblende gneisses from the eclogite to high-pressure granulite facies complex of Cabo Ortegal, NW Spain, show three main geochemical characteristics: (1) low K, Rb, Th and Rb/Sr ratios, and high K/Rb ratios compared with upper crustal rocks; (2) high Ca, low Sr and Ba, low Ba/Sr ratios and high Ca/Sr ratios compared with low – to intermediate – pressure granulite facies gneisses; (3) low REE and absence of positive Eu anomalies compared with granulite-facies gneisses. These geochemical peculiarities reflect the gneisses being residues of partial melting at depths in excess of 35 km, which may have been induced by rise of hot ultramafic diapirs from the underlying mantle.

INTRODUCTION

Cabo Ortegal is a prominent cape at the NW tip of the Iberian Peninsula, some 50 km NE of La Coruña. The Cabo Ortegal complex is situated in the axial zone of the Variscan orogenic belt of the western Iberian Peninsula. It comprises metasediments, metabasic and ultramafic rocks of Early Palaeozoic age (VAN CALSTEREN ET AL., 1979).

The rocks show polycyclic deformation and metamorphism. They now form a semi-elliptical, zoned metamorphic complex, with a central eclogite-facies zone (T = 630-900 °C; P = 14-19 kbar at metamorphic climax; VOGEL, 1967), surrounded by granulite-facies rocks (T = 625-700°; P = 8-10 kbar; DEN TEX ET AL., 1972) and an outer rim of amphibolite-facies rocks (see VOGEL, 1967). The complex is surrounded by almost unmetamorphosed Palaeozoic rocks.

DEN TEX & VOGEL (1962) explained the peculiar situation of the complex as a response to an upthrusted, mushroom-shaped dome. RIES & SHACKLETON (1971) regarded it as an exotic plate of deep crustal material thrust over the Variscan orogenic belt from the west. The presence of a large positive gravity anomaly over the centre of the complex suggests that it is a reflection of a massive deep-rooted autochthonous structure (VAN OVERMEEREN, 1975). VAN CALSTEREN (1978) has proposed that it is the surface expression of a plume of mantle material, diapirs from which thermally metamorphosed pre-existing lower continental crust (the metasediments and metabasic rocks) to granulite facies during crustal rifting. This view is supported by petrographic evidence of the transformation of eclogitic assemblages to high-pressure granulite facies assemblages (author's unpublished data), and by the geochemistry of the ultramafic rocks (VAN CALSTEREN, 1978).

The purpose of this paper is to present geochemical data on Precambrian gneissic rocks from the granulite-facies component of the Cabo Ortegal complex. Irrespective of the structural problems surrounding the origin of the complex, they should provide additional information about geochemical processes at depth in the continental crust. Hitherto, geochemical studies of rocks purporting to represent the deep crust have concentrated on intermediate to high temperature, low- to intermediate-pressure granulite facies complexes (eg. LAMBERT & HEIER, 1968; SIGHINOLFI, 1971; SHERATON ET AL., 1973; DRURY, 1973). Cabo Ortegal reflects a P-T history from depths of 70-35 km at temperatures from 900-625 °C: a high-pressure, intermediate-temperature regime.

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Table I
XRF analytical data. 1 = mean analysis of 16 high-pressure gneisses from Cabo Ortegal; 2 = minimum values in 1; 3 = maximum values in 1;4 = mean analysis of 254 acid to basic gneisses from the intermediate-pressure granulite-facies terrain of the Lewisian, Assynt Scotland (Sheraton et al., 1973); 5 = average composition of the Canadian Precambrian Shield (Shaw et al., 1967). *Total iron expressed as Fe_2O_3.

	1	2	3	4	5
Percent					
SiO_2	60.1	51.3	68.8	61.2	64.9
TiO_2	0.84	0.31	1.7	0.54	0.52
Al_2O_3	14.4	11.7	16.5	15.6	14.6
*Fe_2O_3	8.6	4.9	11.0	5.6	4.1
MnO	0.16	0.11	0.20	0.08	0.07
MgO	3.1	0.7	7.4	3.3	2.2
CaO	7.1	4.2	9.8	5.6	4.1
Na_2O	3.9	2.6	4.9	4.4	3.5
K_2O	0.55	0.17	1.96	1.03	3.1
Parts per million					
Cr	53	18	127	88	99
Ni	29	8	78	58	23
Ba	164	18	524	757	1070
La	13	9	30	20	–
Ce	22	10	46	48	–
Y	25	13	41	9	–
Nb	5	3	19	5	–
Zr	115	71	279	202	400
Sr	292	180	484	569	340
Rb	6.8	0.1	51	11	118
Th	2.4	n.d.	5.6	1	
Ratios					
K/Rb	1970	319	> 10 000	763	220
Rb/Sr	0.032	< 0.001	0.27	0.019	0.35
Ba/Sr	0.63	0.10	2.8	1.3	3.1
K/Ba	26	12	37	11.3	24
Ca/Sr	174	87	276	70	86

Table II
INAA analytical data for four Cabo Ortegal gneisses.
E14: partly mylonitized quartz-plagioclase- biotite-garnet banded gneiss. Playa de Cartes (NE).
E19: quartz-plagioclase-green hornblende (-jadeite-clinozoisite-scapolite) banded gneiss. Playa de Cartes (NE).
E72: quartz-plagioclase-brown hornblende-garnet (-clinozoisite) banded gneiss. San Andres de Teixido.
E77: quartz-plagioclase-green hornblende-garnet (-clinozoisite-scapolite) banded gneiss. San Andres de Teixido.
A: Average post-Archaean Australian sediment (Nance & Taylor, 1976).
B: Average of Archaean amphibolite facies gneisses and tonalitic to granodioritic plutons (author's compilation).
C: Average island arc andesite (Taylor, 1979).
$(Ce/Yb)_N$ = ratio of chondrite-normalized values for Ce and Yb.
Eu/Eu* = ratio of Eu measured to Eu expected in smooth chondrite-normalized REE plot.

	E14	E19	E72	E77	A	B	C
Parts per million							
La	28	10	14	14	38	39	19
Ce	64	19	32	30	80	78	38
Nd	37	12	20	16	32	25	16
Sm	8.0	3.4	5.4	2.8	5.6	5.1	3.7
Eu	2.0	1.19	1.3	0.91	1.1	1.5	1.1
Gd	7.8	4.1	5.3	3.3	4.7	5.0	4.2
Tb	1.2	0.63	0.91	0.54	0.77	0.73	0.64
Tm	0.72	0.36	0.59	0.28	0.5	0.20	0.4
Yb	4.1	2.2	3.6	1.9	2.8	1.1	2.2
Lu	0.66	0.32	0.60	0.31	0.4	0.13	0.3
Th	5.9	1.5	2.1	2.4	10.5	–	2.5
Ta	2.5	1.3	1.6	1.7	–	–	–
Hf	7.3	2.0	3.3	2.5	5.8	–	2.2
Sc	33	39	32	10	–	–	–
Total REE	153	53	84	70	165	156	86
Ratios							
$(Ce/Yb)_N$	4.0	2.1	2.2	4.0	6.0	19	4.5
Eu/Eu*	0.79	0.99	0.77	0.96	0.67	1.0	1.0

ROCKS ANALYSED

The analysed gneisses are coarse, banded, quartzo-feldspathic garnet-hornblende gneisses, enclosed by and containing enclaves of garnet-clinopyroxene metabasic granulites which may have been derived from earlier eclogitic assemblages. They were collected from new road cuttings between Playa de Cartes (N 43°42′, W 4°19′) and San Andres de Teixido (N 43°42′30″, W 4°17′) and from Monte Castrillon (N 43°45′, W 4°11′) (see VOGEL, 1967, Plate 1). They are a minor component of the Bacariza Formation of VOGEL (1967).

The mineralogy of the gneisses is quartz – plagioclase – brown-green hornblende – garnet ± jadeite ± clinozoisite ± kyanite ± scapolite, with rutile as an abundant accessory mineral. This paragenesis is compatible with the P-T conditions derived from the metabasic rocks, and though the gneisses bear little mineralogical resemblance to the pyroxene gneisses of other granulite-facies terrains, their enclosure by high-pressure garnet-clinopyroxene granulites and the occasional presence of jadeite confirms the common history of both components of the Bacariza Formation. That most are not now near-anhydrous pyroxene gneisses implies variable p_{H_2O} during their metamorphism, and that H_2O was not totally purged from them, either as hydrothermal fluids or as migrating anatectic melts.

RESULTS AND COMPARISONS

Table I gives means and ranges for elements analysed by X-ray fluorescence spectrometry at the Department of Geological Sciences, Birmingham University, derived ratios and mean analyses of other suites for comparison. Table II gives abundances in four representative samples for elements analysed by instrumental neutron activation at this laboratory. Details of techniques, precision, accuracy and sensitivity can be obtained from the laboratories involved. Full lists of analyses will be supplied by the author on request.

Though it is not certain whether the gneisses' precursors were igneous or metasedimentary, their bulk composition ranges from dioritic to granodioritic and they have very low K_2O. Compared with calc-alkaline rocks they have high CaO contents. Consequently, all the gneisses show high normative diopside, as do the intermediate-pressure pyroxene gneisses of the Archaean Lewisian complex of Scotland (SHERATON ET AL., 1973).

All the samples show the by now familiar pattern of low K, Rb, Th and presumably U, high K/Rb and low Rb/Sr ratios that characterise intermediate-pressure granulite-facies gneisses. However, compared with the only other high-pressure gneisses that have been analysed, those associated with the eclogitic terrain of Stary Gieraltów, Poland (TARNEY & WINDLEY, 1977), they have higher K/Rb ratios. Together with the Polish rocks they have far lower Sr and Ba compared with low- to intermediate-pressure pyroxene gneisses. Consequently they have higher K/Ba and Ca/Sr ratios. The Ba/Sr ratios are approximately half those in pyroxene gneisses and even lower in comparison with upper crustal materials.

Figure 1 shows chondrite – normalised plots of rare-earth elements (REE) in four of the Cabo Ortegal gneisses. Compared with low- to intermediate-pressure hornblende-biotite gneisses and the average upper continental crust, as represented by post-Archaean sediments, they have low total REE. In contrast to pyroxene gneisses they have low $(Ce/Yb)_N$ ratios and lack positive Eu anomalies. In this respect they resemble the Polish granulites (TARNEY & WINDLEY, 1977, Fig. 4). The REE patterns also resemble those for Phanerozoic andesites.

The Cabo Ortegal and Polish high-pressure gneisses stand together in marked geochemical contrast to the more abundant, low- to intermediate-pressure, granulite-facies, pyroxene gneisses. They are, in addition, markedly different to sedimentary, volcanic and plutonic representatives of the upper crust with similar bulk chemistries, in terms of K, Rb, Th and REE.

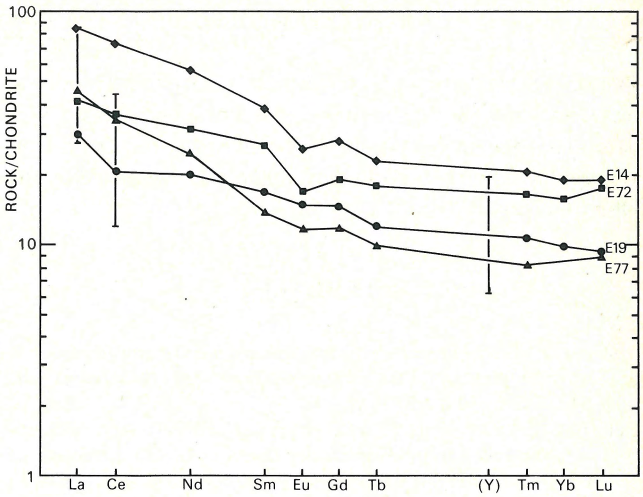

Fig. 1
Rare-earth element abundances in four high-pressure gneisses from Cabo Ortegal, normalized relative to the average of 10 ordinary chondrites (Nakamura, 1974). The range of chondrite-normalized values for La, Ce and Y determined by XRF are given for 16 Cabo Ortegal gneisses.

DISCUSSION

There are three hypotheses to account for the K-, Rb-, Th-, and U-depleted nature of deep crustal rocks:

(1) that they are residues of deep partial melting of the crust, these elements having been carried to higher levels in silicate melts (LAMBERT & HEIER, 1968; SIGHINOLFI, 1971; FYFE, 1973; DEN TEX, 1974)

(2) that these elements were purged from the deep crust, together with H_2O, by 'degassing' of more hydrous precursors (HEIER, 1973; SHERATON ET AL., 1973; DRURY, 1973), probably encouraged by influx of CO_2-rich fluids from the underlying mantle (TARNEY & WINDLEY, 1977; JANARDHAN ET AL., 1979);

(3) that they crystallized directly at the base of the crust from mantle-derived dioritic magmas, these elements being carried to higher levels in the residual, hydrous melt fraction (HOLLAND & LAMBERT, 1975; DRURY, 1978).

Low- to intermediate-pressure pyroxene gneisses, with their high Sr levels and common positive Eu anomalies, satisfy both models 2 and 3 (Drury, in press). The very high Ba levels of those rocks, and the lack of disturbance of their Nd isotope systems, seem to rule out the widespread applicability of model 1 (TARNEY, 1976; HAMILTON ET AL., 1979).

The Cabo Ortegal gneisses, having low Sr and lacking positive Eu anomalies are not compatible with an origin as deep crustal cumulates (model 3). They display no evidence of having been purged of 'volatile' elements by degassing (model 2). In fact they are still quite hydrous, with up to 10% modal hornblende. Removal of anatectic melt fraction with the composition produced by beginning of melting in the quartz-albite-orthoclase-H_2O system should leave a residue that becomes more calcic with increasing degrees of partial melting. Potassium, Rb, Ba and REE will be strongly partitioned into such a melt, thereby depleting the residue in Ba and REE as well as K and Rb, and imposing a low Ba/Sr ratio on the residue. The geochemical peculiarities of the Cabo Ortegal gneisses, including high Ca and low Ba, REE and Ba/Sr are therefore compatible with model 1.

The silicic rocks of the Cabo Ortegal complex are characterised by evidence of late-kinematic anatexis (VOGEL, 1967), possibly under low p_{H_2O} conditions (DEN TEX ET AL., 1972). Such partial melting may have been induced during the eclogite to high-pressure granulite-facies transformation that VAN CALSTEREN (1978) has related to the rise of a mantle diapir. The anatectic sheets found in the complex have the composition quartz-plagioclase-muscovite, and have low K/Rb ratios.

The field and geochemical evidence indicates that the analysed Cabo Ortegal gneisses are residues of deep crustal melting. The present data is incapable of resolving the nature of their precursors partly as a consequence of their very complex history in P – T space.

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