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CABO ORTEGAL, MANTLE PLUMBE OR DOUBLE KLIPPE?[1]

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ABSTRACT

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Petrological, structural and geochemical data are consistent with emplacement of the Cabo Ortegal Complex by two separate Paleozoic thrusting events which elevate successively deeper levels of crust. The existence of only one, premetamorphic, 'ophiolite' suite is argued for Cabo Ortegal, as well as for the other catazonal metamorphic complexes in Galicia.

INTRODUCTION

In the northern part of the central zone of the Hesperian Massif (Fig. 1) several complexes occur (Cabo Ortegal, Bragança, Morais, the blastomylonitic graben, and the periphery of the Ordenes Basin), which are characterized by the presence of rocks with catazonal metamorphic assemblages. Features these units have in common are a remarkably similar polyphase metamorphic and structural history and the presence of major tectonic discontinuities along their margins. The various metamorphic events that have affected these units are best reflected in rocks of basic or ultrabasic chemistry. Thus, the Cabo Ortegal Massif, where these rocks are abundantly represented, has often served as a frame of reference, even in cases where through overemphasizing the similarities and underestimating the importance of the differences – the correlations made may not always have been warranted. In this paper an attempt will be made to reinterpret the observed metamorphic relationships at Cabo Ortegal (VOGEL, 1967; ENGELS, 1972) in such a way that they fit within one orogenic cycle as suggested by DEN TEX (1981a, b), and agree with proposed structural models (RIES & SHACKLETON, 1971; BAYER & MATTE, 1979) as well as with the available isotopic data (VAN CALSTEREN ET AL., 1979).

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GEOLOGICAL SETTING

The rocks at Cabo Ortegal (Fig. 2) can be subdivided in several units that are coherent in a metamorphic as well as in a structural sense (VOGEL, 1967; ENGELS, 1972).

The following three units constitute the central polymetamorphic core of the massif where the rocks are characterized by the presence of catazonal assemblages or relics thereof.

The Concepenido Complex is the uppermost, predominantly metasedimentary unit. It consists of the Banded Gneiss Formation (including the thick continuous eclogite layers at its base), the Cariño gneiss- and the Chimparra gneiss Formations, and the blastomylonitic gneisses found in the Carreiro Thrust Zone.

The Ultramafic Complex consists of a large number of partially serpentinized ultrabasic bodies. The majority of these immediately overlie the Capelada Complex and are erosional remnants of a once continuous sheet. Small, discontinuous occurrences mark the Concepenido complex – Capelada complex boundary in the southern part of the core.

The Capaleda Complex represents the deepest levels exposed at Cabo Ortegal and consists of three predominantly metabasic map units: the Bacariza Formation; Agudo Formation and the Candelaria Granulite Formation. Although a severe

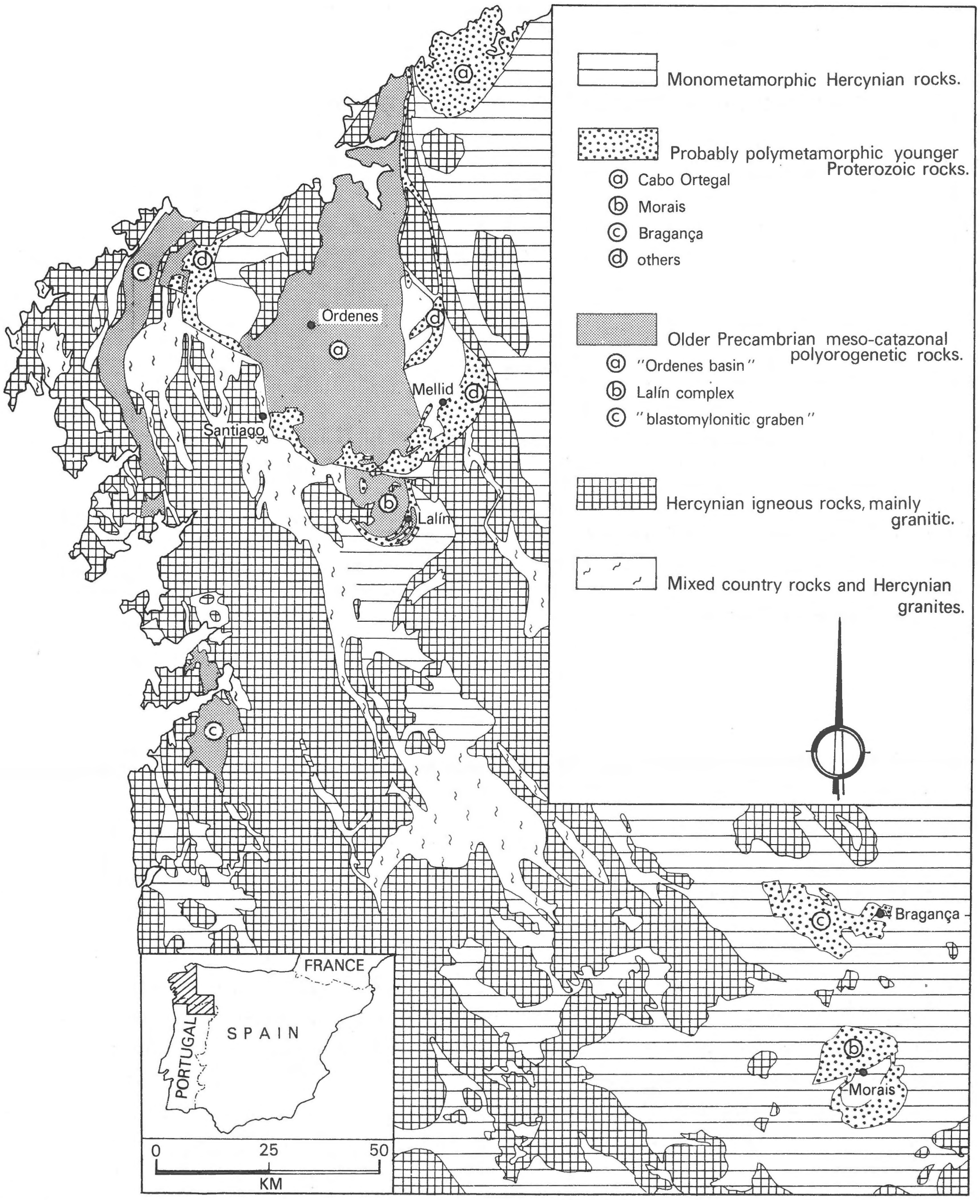

Fig. 1
Location of polymetamorphic complexes in Galicia and N. Portugal.

amphibolite-facies overprint has eradicated most of the evidence, the presence of granulite-facies rock[3] and mineral relics is sufficiently widespread in all three of the formations to establish their common ancestry.

The fourth unit, *the Peña Escrita Complex* constitutes a synformal envelope around this core from which it is separated by a major discontinuity. This discontinuity has been called the Carreiro Thrust Zone along the western side of the massif where it manifests itself as an about 200 m wide zone of tectonically mixed fragments of Purrido Amphibolite, chlorite schist and serpentinite; bordered eastward by the metasedimentary blastomylonite of the Concepenido Complex. Included in the Peña Escrita Complex are the Purrido and Peña Escrita Amphibolites which contain, contrary to the amphibolites of the central core, no relics of a catazonal past. Included also is the Moeche Group at the eastern border of the core (FERNANDEZ POMPA & MONTESERIN LOPEZ, 1976). In this greenschistfacies metamorphic unit sediments, keratophyres and metavolcanic units ascribed to the Upper Silurian occur mixed with folded lenses of serpentinite and with phyllonites retrograde after amphibolite.

[3] plagiopyrigarnite, a rock containing pyralmandine-chloromelanitic clinopyroxene and plagioclase in stable association Vogel, 1967).

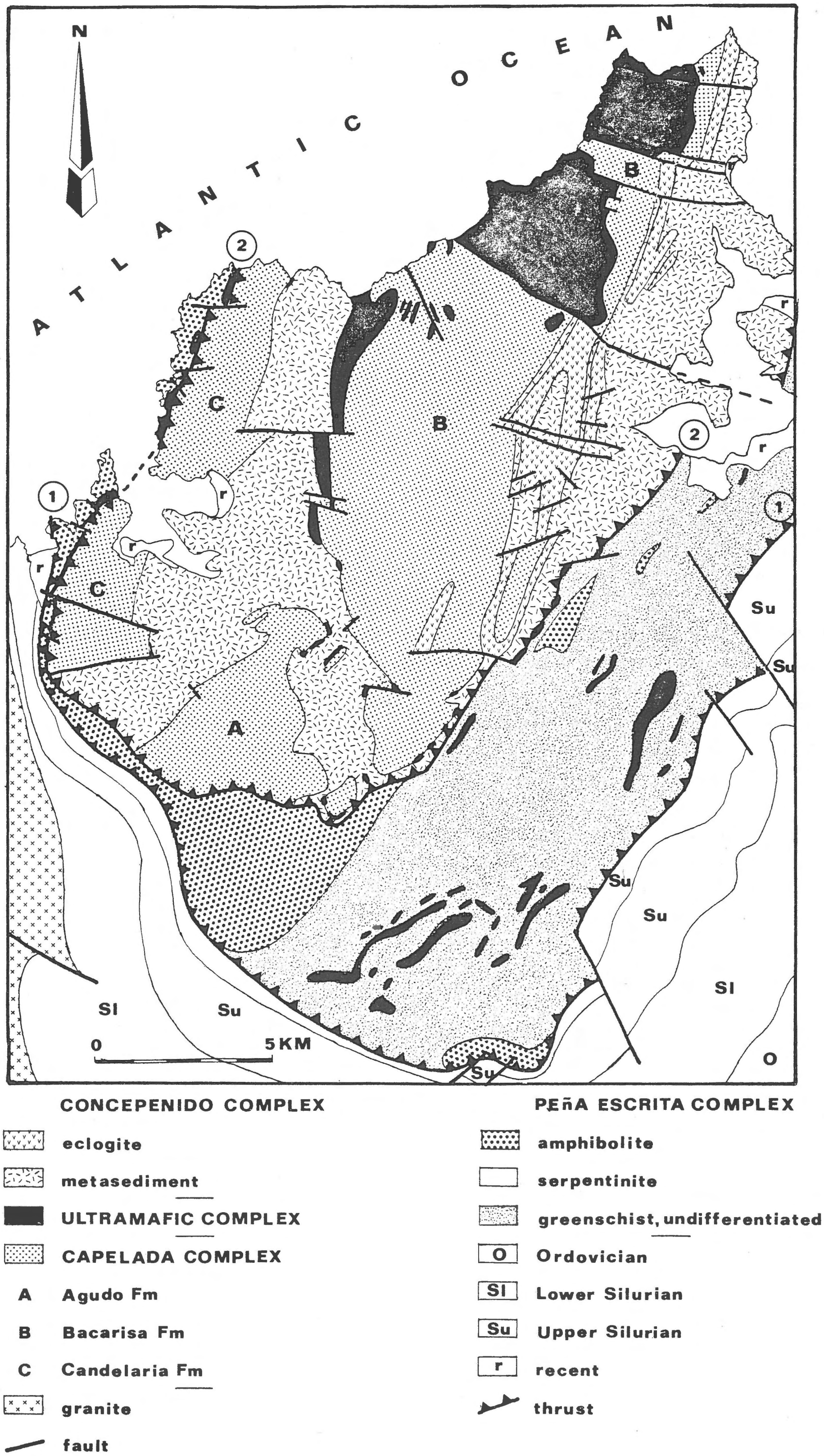

Fig. 2
Sketch map of the Cabo Ortegal complex, data after Vogel and Engels: (Vogel, 1967) and (Fernandez Pompa & Monteserin Lopez, 1976). 1. Southern thrustzone. 2) Carreiro thrustzone with southeasterly continuation

SIGNIFICANCE OF THE ULTRABASIC ROCKS

The role assigned to the ultrabasic rocks in the evolution of the various infracrustal rock complexes has changed with time as more evidence became available;' leading to the following hypotheses:

1. Their emplacement took place in the Precambrian and is penecontemporaneous with the deposition of the precursor sediments of the Banded-, Cariño, and Chimparra gneisses and with the in(ex?)trusion of the basic magmas which are parental to eclogites and plagiopyrigarnites. The sequential appearance of green spinel, garnet, and colourless pargasite + chlorite as characteristic minerals in the asemblage is seen as evidence that metabasites and meta-ultrabasites (including those of the Carreiro thrust zone) share a common metamorphic history (VOGEL, 1967).

2. The occurrence of ultrabasites associated with greenschists ascribed to the Siluro-Devonian in the Moeche Group leads KONING (1966) to propose the existence of two ophiolite sequences, a Precambrian one and a Lower Paleozoic one.

3. The ultrabasic rocks of the polymethomarphic core were emplaced during the Precambrian and share a common metamorphic history with the metabasites. Fe-Mg partitioning data, however, indicate that green spinel and garnet were formed in the mantle, prior to emplacement, MAANKANT, 1970).

4. The ultrabasic rocks represent a mantle plume emplaced during the Early Paleozoic (around 500 Ma). The emplacement of the plume caused catazonal metamorphism of the crustal rocks it intruded (sediments and associated gabbros of continental affinity) and was itself a source for less basic intrusive sequences such as gabbroic rocks with an oceanic signature (Purrido- and Peña Escrita amphibolites) and calc-alkaline and peralkaline granites (VAN CALSTEREN, 1977).

5. The mantle plume activity started more than 600 Ma ago, but postdated the first catazonal (eclogite facies) metamorphic phase (M_0). It was responsible, however, for a catazonal metamorphic overprint (M_1) of granulite facies metamorphic assemblages (plagioclase stable beside garnet and clinopyroxene) on eclogite facies ones (DEN TEX, 1981a).

To evaluate whether these models are applicable to the situation at Cabo Ortegal it is necessary to consult the metamorphic testimony as presented in the associated rocks.

THE BASIC ROCKS OF THE POLYMETAMORPHIC CORE

The sequence of metamorphic events in the infracrustal rock complexes is best documented in the rocks of basic chemistry. At Cabo Ortegal it has led to the distinction of four consecutive metamorphic events (see Table 1).

M_1 A major event during which gabbroic and possibly basaltic rocks were transformed into eclogites and plagiopyrigarnites at high temperatures and pressures. At shallower levels (Cariño gneiss, upper level of the Chimparra gneiss) catazonal conditions were not attained. Here the basic rocks were transformed into amphibolites. Relics that have partially survived the M_1 metamorphism and the consecutive metamorphic phases include rocks ranging from olivine gabbro to norite. These are then transformed into eclogites and plagiopyrigarnites via an intermediary coronitic stage where garnet is formed according to a reaction of the following general type:

Olivine (or orthopyroxene) + anorthite $\leftrightarrows$ garnet (+ quartz) (1)

In the completely metamorphosed rock this may lead to a honeycomb structure in which the reticular arrangement of the garnets (Fig. 3) testifies to the shallow crustal origin of the parent rock. These honeycomb structures were found in eclogites as well as in plagiopyrigarnites. They also occur in phengite eclogites of the blastomylonitic graben and in eclogites from the rim of the Ordenes Basin (C.E.S. ARPS and R. KUYPER, pers.comm.).

Table 1

	ECLOGITES	PLAGIOPYRIGARNITES	PERIDOTITES cpx.opx.ol in all assemblages except serpentinites	Purrido-type amphibolites
Pre M	cpx + plag + ol		green spinel	cpx + plag + ol
M_1	gt + omph	gt + cpx + plag	garnet	green hbl + plag
M_2	gt + cpx + plag ± brown hbl		green pargasite?	——
M_3	green hbl + plag ± gt		colorless pargasite + brown spinel	chlo + act + ab + ep
M_4	minor alterations		serpentine	chlo + act + ab + ep

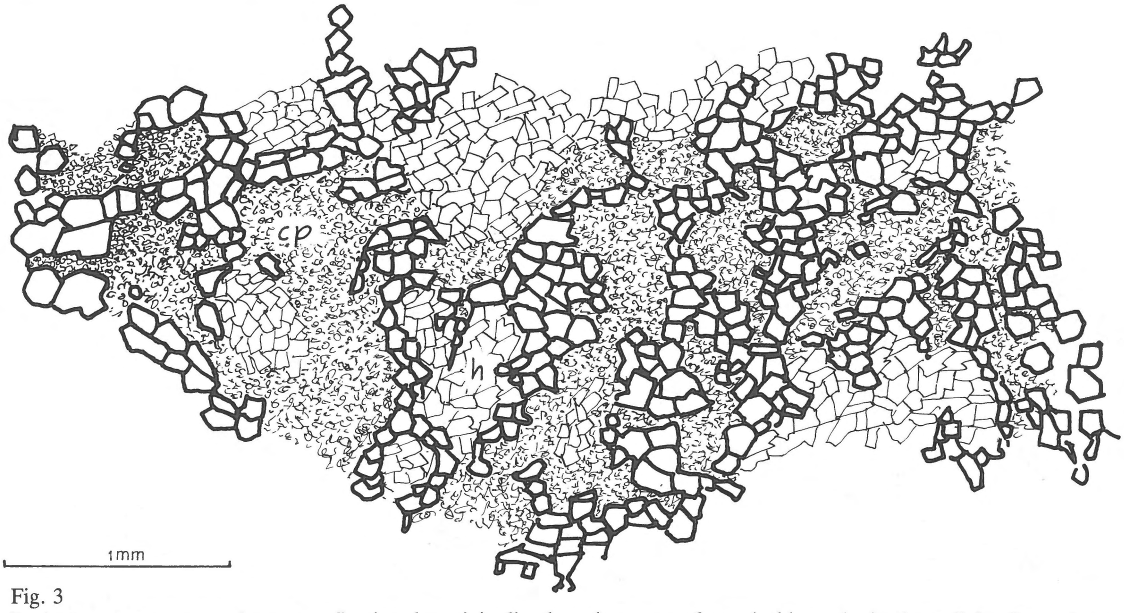

Fig. 3
Reticular arrangement of garnet reflecting the originally plutonic nature of a carinthine eclogite from Cabo Ortegal. cp = omphacite; h = brown amphibole (carinthine). Sample st 140137,

For the eclogites (Fig. 4) metamorphic conditions during M_1 can be estimated fairly accurately by combining the geothermometers of KUSHIRO (1969; based on the jadeite content of the omphacite) and RÅHEIM & GREEN (1974; based on partitioning of Fe and Mg between coexisting garnet and clinopyroxene). RÅHEIM & GREEN's thermometer is preferred over those of GANGULY (1979) and SAXENA (1979) because the temperatures calculated according to their method agree best with that (560°) obtained from ADDY & GARLICK's (1974) quartz rutile thermometer.

Fig. 4 shows that P-T conditions (560-630°, 8-12 kbar) for eclogite formation at Cabo Ortegal lie close both to the oceanic geotherm and to the eclogite-garnet granulite transition as defined by GREEN & RINGWOOD (1967), as is to be expected since eclogites and plagiopyrigarnites (garnet granulites) occur closely associated in the field. They furthermore straddle the staurolite stability field in accordance with the observed occurrence of staurolite in gneisses intercalated with eclogites.

For plagiopyrigarnites from the margin of the Ordenes Basin K_D-values for garnet-clinopyroxene pairs (HUBREGTSE, 1973) indicate a similar temperature interval (530-720°) if it is assumed that they should plot in the garnet granulite field and that pressures were comparable to those at Cabo Ortegal.

Since the presence of pargasite as a costable ferromagnesian phase may have influenced Fe-Mg partitioning between garnet and clinopyroxene in these plagiopyrigarnites, it is uncertain, however, to what extent the calculated temperatures reflect reality. A similar observation applies to the garnetpyroxenite veins in the ultrabasic rocks (see below), where orthopyroxene coexists with garnet and clinopyroxene).

The phengite eclogites of the Blastomylonitic Graben (VAN DER WEGEN, 1978) were formed at considerably higher pressures (13-20 kbar) which is consistent with the lack of associated plagiopyrigarnites. Since true eclogites can, apparently, only form at gradients lower than the oceanic geotherm (± 17°/km) it seems more appropriate to ascribe their formation to simple burial than to the thermal influence of a mantle plume.

M_2, at Cabo Ortegal, is but a minor event. It is mainly noticeable in the eclogites, where it is held responsible for the symplectitization of omphacite, and where sodic plagioclase, held in solid solution in the omphacite, is exsolved according to:

$$\underset{}{CaAl_2Si_4O_{12}}^* + \underset{\text{jadeite}}{Na_2Al_2Si_4O_{12}} \leftrightarrows \underset{\text{oligoclase}}{CaNa_2Al_4Si_8O_{12}} \qquad (2)$$

It thereby stabilizes the eclogite-facies assemblage in the clinopyroxene-almandine subfacies of the granulite facies. When this transformation happened in the presence of water, some amphibole (γ brown to greenish brown) may have formed in addition. In the plagiopyrigarnites, where garnet, clinopyroxene and plagioclase already are stably associated, slight tectonization and the appearance of a similar amphibole are the only signs M_2 has left. Fig. 4 shows that a slight change in P-T conditions will suffice at Cabo Ortegal to bring the eclogites into the 'garnet granulite' field.

During the M_3 phase the association garnet-clinopyroxene becomes unstable in the rocks of basic composition as is

* a hypothetical clinopyroxene end member (Vogel, 1966).

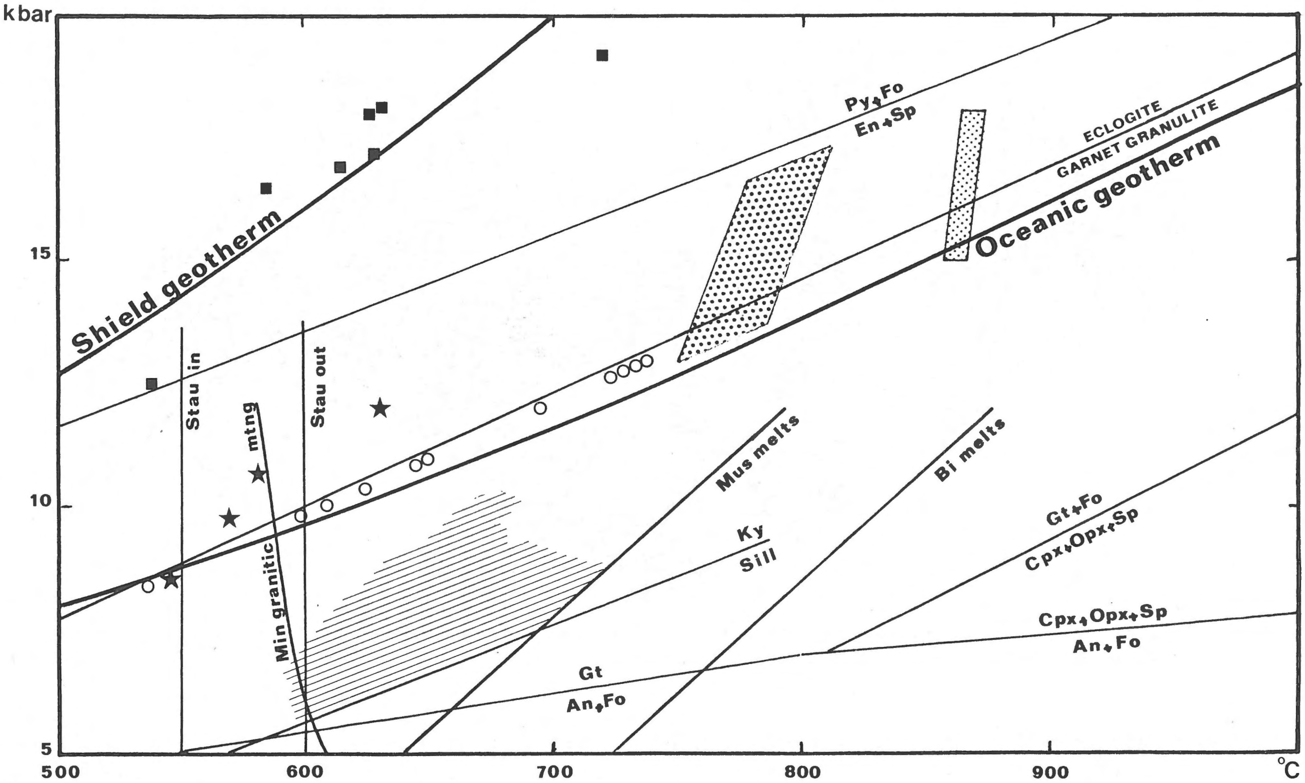

Fig. 4
Pressure-temperature diagram indicating metamorphic conditions for the formation of eclogites from the Blasto mylonitic graben (squares), the Cabo Ortegal complex (stars) and for plagiopyrigarnites from the margin of the Ordenes Basin (circles). Hatched field: presumed P-T conditions during M_3 amphibolite facies metamorphism. Dotted signatures: possible P-T combinations for the garnet-pyroxenites in the ultrabasic rocks according to Råheim & Green (1974, coarse dots) and Ganguly (1979, fine dots). Data after Den Tex, 1965; Fyfe, 1973; Green & Ringwood, 1967; Hyndman, 1972; Kushiro & Yoder, 1966.

testified by the development of kelyphitic rims consisting of hornblende (γ bluish green), plagioclase, and magnetite around the garnets. Rutile is replaced by sphene. That access of water is important is evident in eclogites and plagiopyrigarnites alike. Amphibolization is always most complete in zones that have been tectonized. In lenticular relics that escaped deformation, catazonal assemblages are usually preserved while in the tectonized rocks only stray garnet or clinopyroxene crystals or rutile cores in the sphene testify to a catazonal past.

As far as metamorphic conditions are concerned, staurolite is no longer a stable phase during M_3. Kyanite is always the stabe Al_2SiO_5 polymorph, and muscovite has not participated in any partial melting of the metasedimentary rocks. This restricts the P-T conditions during M_3 to 600-700; 6-8 kbar at a geothermal gradient not exceeding 28°/km (see Fig. 4).

Evidence of the M_4 phase in the central polymetamorphic core is mainly restricted to the ultrabasic rocks. Occasional saussuritization of the plagioclase and the formation of some chlorite, pistacite or prehnite along narrow veinlets are the only manifestation of M_4 in the basic rocks.

THE ULTRABASIC ROCKS OF THE POLYMETAMORPHIC CORE

A sequential appearance of typomorphic minerals (green spinel; garnet/green pargasite; edenite ± chlorite; chrysotile) indicates that, like the basic rocks, the ultrabasic rocks have reequilibrated several times during their existence.

Contrary to MAASKANT's (1970) view that several of these reequilibrations took place in the mantle prior to emplacement, it is argued here that they represent adaptations to the same metamorphic phases that have affected the basic rocks under crustal conditions.

Pre M_1. The oldest mineral-reaction relationship that can be established at Cabo Ortegal is the formation of garnet from a green spinal s.s.. The relationship has only been observed in narrow garnet pyroxenite veins of picritic compositon. These crosscut the main peridotite bodies and possibly represent late-stage differentiates of the ultrabasic magma.

The spinel itself is in all probability no primary mineral since WARNAARS (1967) describes its formation from plagioclase and olivine in plagioclase wehrlites in the western margin of the Ordenes Basin. He interpreted the symplectitic spinel-orthopyroxene intergrowths that occur between plagioclase and olivine as reaction rims due to the reaction:

$$\underset{\text{anorthite}}{CaAl_2Si_2O_8} + \underset{\text{forsterite}}{2Mg_2SiO_4} \leftrightarrows \underset{\text{spinel}}{MgAl_2O_4} + \underset{\text{diopside}}{CaMgSi_2O_6} + \underset{\text{enstatite}}{2MgSiO_3} \tag{3}$$

If a similar way of formation is also envisaged for the spinel found at Cabo Ortegal, a shallow ($P < 7$ kbar), rather than a deep MAASKANT (1970) emplacement is indicated for the ultrabasic rocks (see Fig. 4). BONATTI ET AL. (1981) interpreted similarly associated spinel- and plagioclase lherzolites from the Red Sea rift-zone (Zabargad Island) as representatives of an oceanic upper mantle.

M_1-M_2. As burial of the ultrabasic rocks ensued, spinel became unstable and was replaced by garnet according to:

$$\underset{\text{spinel}}{MgAl_2O_4} + \underset{\text{diopside}}{CaMgSi_2O_6} + \underset{\text{enstatite}}{2MgSiO_3} \leftrightarrows \underset{\text{garnet}}{CaMgSi_2Al_2O_{12}} + \underset{\text{forsterite}}{Mg_2SiO_4} \tag{4}$$

That this reaction and not:

$$\underset{\text{spinel}}{MgAl_2O_4} + \underset{\text{enstatite}}{4MgSiO_3} \leftrightarrows \underset{\text{pyrope}}{Mg_3Al_2Si_3O_{12}} + \underset{\text{forsterite}}{Mg_2SiO_4} \tag{5}$$

is responsible for the formation of garnet in the ultrabasic rocks is indicated by the fact that the garnets in peridotites and pyroxenites from Cabo Ortegal as well as those from the margin in the Ordenes Basin have grossular contents varying between 11.0 and 16.6% (MAASKANT, 1970).

Application of the thermometer of RÅHEIM & GREEN (1974) to garnet-clinopyroxene pairs from the garnet pyroxenites (for analyses see MAASKANT, 1970) shows that the equilibration temperatures for this assemblage (Fig. 4) can be reconciled with those calculated for eclogites and plagiopyrigarnites, and that the occurrence of garnet in the ultrabasic rocks can be attributed to the M_1 (M_2) metamorphic phase.

An early generation of pale green pargasite (deformed during deformation contemporaneous with M_3) may represent the hydrous equivalent of garnet in the M_1-M_2 assemblage. WARNAARS (1967) described reaction rims of this type of pargasite around spinel in the amphibole wehrlites of the Castriz area.

M3. The formation of idioblasts of chlorite and colourless pargasite-edenite is ascribed to the recrystallization of the ultrabasic rocks under amphibolite-facies conditions. Although in principle garnet should be stable at the presumed pressures and temperatures (Fig. 4), coronas consisting of symplectitically intergrown edenite and picotite are formed around the garnet.

The colourless amphibole which has a composition about midway between pargasite and edenite must have formed according to a reaction of the following general type:

$$\underset{\text{garnet}}{Ca_{0.6}Mg_{2.4}(Al,Cr)_2Si_3O_{12}} + \underset{\text{clinopyroxene}}{NaCaMgAlSi_4O_{12}} + \underset{\text{forsterite}}{3Mg_2SiO_4} + H_2O \leftrightarrows \tag{6}$$

$$\leftrightarrows \underset{\text{edenite}}{Na(Ca_{1.6}Mg_{0.4})Mg_5(AlSi_7)O_{22}(OH)_2} + \underset{\text{picotite}}{Mg(Cr,Al)_2O_4} + \underset{\text{enstatite}}{3MgSiO_3}$$

In reality (MAASKANT, 1970) the edenites also have some Al^{IV}-Al^{VI} substitution which can be obtained by postulating a more aluminous clinopyroxene with a similar substitution. Also the A site of the analysed amphiboles is never completely filled, which is a reflection of the Na-poor nature of the clinopyroxenes available for reaction.

M_4. During M_4 the peridotites were again deformed, but this time deformation took place along narrow shear zones where virtually complete serpentinization took place under conditions estimated to be those of the greenschist facies. In the roughly lenticular bodies between the shear zones, serpentinization is less complete and visible effects of internal deformation are lacking.

Summarizing it can thus be argued that the peridotites of the polymetamorphic core were emplaced at a fairly shallow level ($P < 7$ kbar) prior to the M_1 phase of metamorphism. Their internal mineralogical relationships indicated that progradation (spinel $\rightarrow$ garnet) took place during ever deeper burial and was followed by retrograde metamorphism (garnet $\leftrightarrows$ edenite $\leftrightarrows$ serpentinization) in several steps.

BASIC AND ULTRABASIC ROCKS OF THE PENA ESCRITA COMPLEX

The absence of catazonal relics in the Purrido- and Peña Escrita amphibolites, has led to the supposition that they represented post-M_2 intrusions of gabbroic magma that were converted into amphibolite during M_3, followed by tectonization during M_4 at which time the plagioclase became saussuritized and the amphibolites converted in chlorite schist along thrust planes, (VOGEL, 1967). This postulation was lent credence by VAN CALSTEREN (1977) who established that their chemistry was fundamentally different from that of the metabasites in the polymetamorphic core.

Likewise in the associated ultrabasic rocks, edenite is the highestgrade typomorphic mineral observed in the Carreiro Thrust Zone, as it also is for instance in the Castriz area (WARNAARS, 1967) or the low grade unit of the Mellid area (HUBREGTSE, 1973a) on the western and south-eastern side of the Ordenes basin.

The ultrabasic rocks of the Moeche Group have been serpentinized so severely that only picotite has survived as a recognizable phase according to FERNANDEZ POMPA & MONTESERIN LOPEZ (1976).

THE ISOTOPIC EVIDENCE

Attempts to determine the age of the various metamorphic events by dating their characteristic amphiboles by means of the K/Ar method (VAN CALSTEREN ET AL., 1979) failed in so far that in the polymetamorphic core amphiboles ascribed to M_2

cluster around the same age 390 ± 25 Ma as those typical for M_3; while the highest ages (477 and 431 Ma) were recorded on amphiboles from amphibolites in the Peña Escrita Complex.

A similar apparent contradiction concerns the age of the La Pioza eclogite of the Blastomylonitic Graben. Petroghraphic relationships indicate that the phengite is co-stable with garnet and omphacite (M_1). Nevertheless its Rb/Sr age was determined at 370 ± 4 Ma and its K/Ar age at 330 ± 7 Ma (VAN CALSTEREN ET AL., 1979) both too young to represent an M_1 event that must predate the Silurian. Since the graben-eclogites were formed at temperatures between 520° and 700° (Fig. 4) and blocking temperatures of Rb/Sr and K/Ar in phengite are 500 ± 50°C and 350°C ± 50°C respectively (JÄGER, 1979) these data must mean that until 350 Ma ago the graben-eclogites were buried at depths below the 500° isotherm while they passed the 350° isotherm around 330 Ma. This indicates a cooling rate of 3.75°/Ma, much lower than the 20°-50°/Ma considered normal by HUNZICKER (1979), showing that rates of uplift must have been very slow indeed for the Blastomylonitic Graben.

If the K/Ar ages of the Cabo Ortegal amphiboles are likewise considered to be cooling ages, they indicate that the uplift of the Peña Escrita Complex to a level above the amphibole blocking temperature must have occurred some 60-90 million years before the central polymetamorphic core passed the same level.

If this reasoning is correct, the Peña Escrita Complex and the polymetamorphic core represent two completely separate units. It is then no longer necessary that metamorphic phases of the one are exactly duplicated in the other. The Peña Escrita Complex may thus represent the ophiolite suite (if the term may be used for so incomplete a sequence) from a different part of the basin that was buried at shallower depth than the polymetamorphic core. While for the latter catazonal conditions were reached (M_1-M_2), the former was never metamorphosed beyond amphibolite-facies grade (see Table 1). As such it is comparable to the Castriz peridotites (WARNAARS, 1967) the low-grade complex at Mellid (HUBREGTSE, 1973a), and the Lalin Unit in which HILGEN (1971) established the existence of two successive phases of amphibolite-facies metamorphism, ascribing the first one to a pre-Hercynian event.

M_3 then would represent the first phase of uplift, at the end of which the amphibolite-facies rocks of the Peña Escrita Complex are thrust over Upper Silurian strata close to the surface, while at the same time the polymetamorphic core is brought up to the amphibolite-facies level.

Along the thrust plane, the amphibolites of the Peña Escrita Complex are phyllonitized and converted into greenschists, the associated ultrabasic rocks are boudinaged, folded, and serpentinized. Both are mixed with low grade metamorphic material of the Upper Silurian to form a 'mélange': the Moeche Group.

At deeper levels the polymetamorphic core is internally severely tectonized under mesozonal conditions. The catazonal metagabbros are in large part transformed into foliated amphibolites. The ultrabasic rocks are folded and boudinaged and developed edenite-(chlorite)-picotite bearing assemblages. The gneisses were subjected to incipient partial melting, were overridden on the western side of the complex by amphibolites and ultrabasic rocks and became mylonitized in the process.

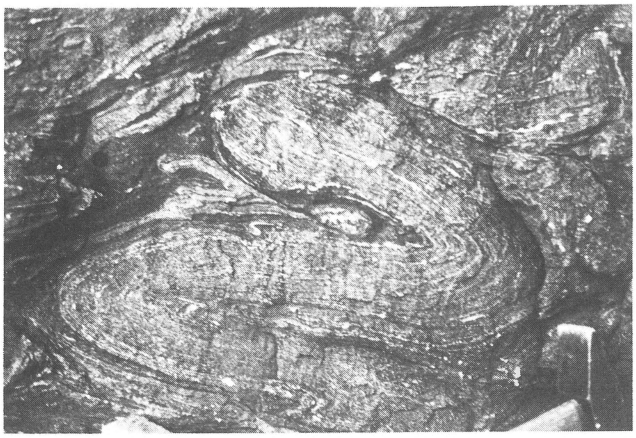

Fig. 5
Folded 'monophase' amphibolite boudin bedded in chlorite (actinolite) schist.

Uplift of the polymethamorphic complex continued or resumed after the Peña Escrita Complex was emplaced. Thrusting of the blastomylonites over the ultramafic cover of the Purrido Amphibolites caused the latter to be folded or to be partially converted into greenschists (Fig. 5) while the ultrabasic rocks in the Carreiro Thrust zone were boudinaged, serpentinized and deformed internally. The exact timing of these events is difficult to establish without more precise data on blocking temperatures for the amphibole K/Ar system, P-T conditions during the M_1 and the M_3 metamorphic events, and rates of cooling and uplift.

From Fig. 4 it seems as if the geothermal gradient was suddenly raised from 17°/km during M_1 to 26°/km during M_3. This could occur if cooling could not keep pace with the rate of uplift so that hot catazonal rocks found themselves all of a sudden in fairly shallow (21-30 km deep) crust after the first phase of uplift. This phase must have started at or before 450 Ma (average age of the amphiboles dated) and been completed at or after 405 Ma (approximate age of the overthrust surface rocks). The second phase of uplift started at or before 390 Ma (average K/Ar age of the amphiboles in the polymetamorphic core) and may have continued well into the Carboniferous. It is after all probably not fortuitous that:

1) Uplift started before 450 Ma; resumed before 390 Ma and terminated after 330 Ma, and the various granitic suites (VAN CALSTEREN, 1977) have Rb/Sr ages of 460-470 Ma, 409 ± 24 Ma, and 318 ± 21 Ma.

2) The cooling rate for the blastomylonitic graben when extrapolated back in time indicates a minimum age of 402 Ma for the eclogitic equilibrium assemblage (Fig. 4).

3) Both the emplacement of the Mondoñedo nappe at post Wenlock times (MARTINEZ CATALÁN, 1980), and the décollement tectonics of the Hercynian Cordillera (intra-Westphalian according to JULIVERT, 1971) occurred at times close to the culmination of the two phases of uplift in Western Galicia.

DISCUSSION

If the concept of multiple thrusting is accepted, it is, at least as far as Cabo Ortegal is concerned, no longer necessary to postulate the existence of two separate ophiolite suites. Instead, the various ophiolite occurrences could represent different sections of a single ophiolitic (oceanic?) basement on which deposition of clastic sediments took place at a time estimated by KUYPER ET AL. (1982) to lie somewhere between 1000 and 1500 Ma ago, a figure not at odds with the 1300 Ma postulated for oceanic crust in the South Brittany Metamorphic Belt (PEUCAT ET AL., 1981).

Relict mineral associations in some of the less metamorphosed ultrabasic rocks (plagioclase; orthopyroxene-spinel symplectite rims around plagioclase) indicate shallow ($P < 7$ kbar) emplacement, consistent with the idea that together with the 'oceanic' metagabbros they represent oceanic crust either newly formed above a mantle plume (VAN CALSTEREN ET AL., 1979), or emplaced along the Pre-Cambrian equivalent of a midoceanic ridge.

Intrusion of gabbroic magma with a continental chemical signature must postdate this event and can be placed roughly coincident with the start of sedimentation since the metabasites (eclogites, plagiopyrigarnites) occur intercalated between the metasediments. It must have occurred, however, before the sediments were too deeply buried since eclogites as well as plagiopyrigarnites and amphibolites show relict ophitic (ARPS ET AL., 1977) and reticular textures. Burial of the oceanic crust and its sedimentary cover is held responsible for the M_1 phase of metamorphism. It must have reached depths of about 45 km for the polymetamorphic core at Cabo Ortegal, about 60 km for the eclogites from the Blastomylonitic Graben, but only about 30 km for units such as the Peña Escrita Complex at Cabo Ortegal, the ophiolites near Castriz, the 'Hercynian ophiolitic rocks' of Mellid, or the Lalin Unit.

The metamorphic assemblages suggest very low geothermal gradients at this time corresponding to a heat flow of about 1 HFU or less, indicating that the effects of mantle plume or midoceanic ridge had long since waned.

A tensional regime, heralded by Late-Proterozoic-Early Cambrian block faulting (VAN DER MEER MOHR ET AL., 1981) must have persisted during much of the Paleozoic, causing uplift of the deeply buried rocks on a set of listric faults, thus producing horst-graben tectonics at the surface and thrusting at deeper levels.

During a first event, which may have started as early as M_2 but is coeval with M_3 the mesozonal parts of the basin are thrust over metasedimentary rocks close to the surface (1, in Fig. 2). The catazonal parts are brought up to the mesozone level. The increase of the geothermal gradient coincident with this event, is thought to be an effect of a rate of ascent which outpaces the capacity of the rocks to disseminate their heat, rather than an expression of deep-seated plutonic activity. Heat flow (equivalent to about 2 HFU) was too low to warrant the postulation of a mantle plume at this stage. From the time registered by the amphiboles as they cooled below their blocking temperatures this uplift must have started before 450 Ma and continued to at least 395 Ma, since that is the age of the sediments that were overthrust. 390 Ma is also the average time at which the amphiboles of the polymetamorphic core have cooled sufficiently to close their K-Ar system. The core continued to rise and was ultimately thrust over the mesozonal part of the basin. This type of superposition (catazonal on mesozonal) may also have occurred in the Ordenes Basin and in Portugal since in all cases (ANTHONIOZ, 1967a, b; HUBREGTSE, 1973a; KUYPER, 1981) the catazonal complexes are fault-bounded and seem to overlie lower grade metamorphic rocks. The occurrence of large-scale décollements in the superstructure at the appropriate times in the polyphase uplift may indicate that the basement was not only active in Western Galicia but possibly as far East as Mondoñedo.

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