THE PETROLOGY OF THE REGION BETWEEN LAGE AND CARBALLO

(NW GALICIA, NW SPAIN)

BY

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INTRODUCTION

The area investigated comprises a 5 miles broad E-W belt mainly through the group of rocks called "Complejo Antiguo" by professor Parga-Pondal (1956). The section runs roughly from the village of Lage on the west coast eastwards towards Carballo.

The object was to detect the various relationships between the rocks of this group; more especially it is an attempt to elucidate the metamorphic history of this so-called Ancient complex in terms of a scheme of syn-, late- and post-kinematic metamorphic events.

The frequent occurrence of bands of basic rocks, syngenetic in origin within the surrounding schists and paragneisses, was a great help in the interpretation because of their susceptibility to metamorphism. No attempt has yet been made to describe and interpret the physiography of the area, neither has much attention been paid to the petrochemistry and petrofabrics of the rocks involved, although these branches of knowledge are indispensable for a final conclusion on their origin and history. This investigation is partly based on the previous work, done by professor Parga-Pondal and our results are a mere extension and revision of his ideas and concepts. I want to express my thanks for the assistance and the continual hospitality offered by him and his family. The present study has been guided by Prof. Dr. L. U. de Sitter and Dr. H. J. Zwart of the Geological and Mineralogical Institute of Leyden University, and forms part of a much more extensive survey by this Institute, now under the direction of Prof. Dr. E. den Tex.

Parga distinguishes three main north-south running zones of rocks: the Ancient complex in the center, flanked on both sides by rocks of the Lage group and a large mass of basic rocks in the east. In order to avoid the implications of this terminology, we propose to call these groups:

western Lage group	→ Lage group
Ancient complex	→ Central complex
eastern Lage zone	→ Pico de Meda group
Basic complex	→ Basic complex

The Lage group s.s. contains younger granite intrusions and numerous younger acid and basic rock dykes with a NW-SE strike and in which contemporaneous basic rocks are virtually lacking. This group of rocks which will not be described in this paper consists mainly of a muscovite-biotite bearing granitic gneiss with frequent granitic patches and a large zone of ordinary pegmatites. These gneisses enclose broad zones of micaschists. The schistosity is mostly vertical but flattens occasionally towards the coast. Occasionally the gneisses are linear. In the gneiss ghost structures of folds can sometimes be observed.

The Central complex shows a much greater variety of rocks, augen, linear, planar, leptynitic and hornblende gneisses, migmatites and granites, several kinds of micaschists and frequently basic rocks with eclogite affinities.

The Pico de Meda group of rocks, between the Central complex and the Basic complex will be described here in some detail. It contains linear and augengneisses, migmatites and granites and shows a mineralization of tungsten and tin. Moreover we find here again micaschists containing numerous basic zones. Finally we arrive in the east in the Basic complex with amphibolites, gabbro's and a zone of peridotites and serpentinites.

The present paper is principally concerned with the basic rocks occurring in the Central complex and in the Basic complex with its western boundary region.

As the origin and the history of the Basic rocks cannot be rightly judged without a knowledge of the surrounding rocks, a description of the other rocks of the Central complex, the eastern zone of Pico de Meda gneisses and migmatites, and the micaschists between this rather narrow zone and the Basic complex will first be given.

The distinctly younger, NW striking, non-tectonized acid and basic dykes have not been studied. Neither have we paid much attention to the biotite-granodiorite of Bayo, which contains dislocated xenoliths and parallel inclusions of the surrounding gneiss. Its contact with the Borneiro gneiss is sharp. The rock is often characterized by oriented feldspar megacrysts, probably a flow structure. The gneissose trend of the Borneiro gneiss can be followed into this granodiorite as faintly expressed shears. Thus the Bayo granodiorite gives the impression of being a late kinematic intrusive rock.

The country is badly exposed except on the top of the hills. It is either covered by pine woods with an often almost impenetrable undergrowth of "toja", a very prickly kind of gorse, or with maize fields. In particular the two aplanation surfaces, one at about 200 m alt., the other at 400 m alt. are extremely poor in outcrops.

Moreover the rocks are very deeply weathered except again on the hill tops.

THE CENTRAL COMPLEX

The Central complex zone contains the following rock types:

(1) muscovite-gneisses, quartzitic gneisses and hornblende gneisses, characterized by a marked schistosity due to planar orientation of the minerals in question;
(2) linear gneisses, augen-gneisses, migmatic gneisses, granite;
(3) feldspathic schists, graphitic schists, micaschists and hornfelses.

All of these rocks except the linear gneisses contain basic rocks occurring as parallel layers of varying thickness, which will be treated separately. The Central complex is typified by these strongly linear and schistose augengneisses, as displayed for instance in the Sierra de Borneiro. However, non-linear, more schistose, often thinly foliated gneisses of the first group are frequently found.

From the alternation of micaceous bands in the gneisses and the presence of boudinaged basic intercalations, of graphitic micaschists and of leptynitic gneisses in augen- and migmatitic gneisses, a sedimentary origin for the rocks belonging to the Central complex can be deduced. The majority of the gneisses of the Central complex are thus paragneisses with a typical macroscopical habit, different from the less linear gneisses of the Lage group. However, some gneisses of the Lagegroup resemble macroscopically the leptynitic and leucocratic gneisses of the Central complex.

The foliation of the gneisses of the complex is typically subhorizontal or it dips eastwards with angles up to 40°. Lineations plunge consistently southwards with angles from 5°—20°. The linear gneiss, shown on the map, is a very pronounced B-tectonite, with pencil shaped feldspar rods. In the augengneiss of the Sierra de Borneiro and in some other gneisses of the Central complex the trend of the lineation is slightly discordant in relation to the regional trend and lithological boundaries. This discordant strike (345° NNW) is probably of an early origin, because the later microfolding of S-planes is parallel to the regional trend (20° NNE) and is also topographically expressed by the trend of the Borneiro ridge. In the Central complex the gneisses occur in three successive ridges, separated by valleys consisting of micaschists.

The augengneiss of Borneiro

This rock complex forms the easternmost ridge of the Central complex and consists of linear augengneisses with large eye-shaped feldspar porphyroblasts. The rocks change into a linear gneisses when the feldspars become smaller, and finally into planar gneisses and feldspathic micaschists. The long axis of the augen is mostly parallel to the visible lineation of the rock but occasionally discordant megacrysts occur.

Under the microscope the strongly expressed linear character is for a large part lost. The feldspar augen, consisting of microcline-microperthite show recrystallization in varying degrees into small crystals of potassium feldspar, albite and quartz. The recrystallization starts from the circumference or cracks in the large crystals, and is accompanied by new small oriented mica flakes surrounding the remnants of the augen. Garnet crystals, obviously belonging to the earlier minerals, have been cracked or squeezed into streaks and have often been replaced by clinozoisite. In these cracks and streaks occurs also chloritized biotite. The quartz and feldspars often show wavy extinction and cataclastic boundary zones, indicating a late phase of shearing.

Basic rocks are relatively abundant, sometimes as frequent as twelve separate occurrences in a 50 m section; they vary in thickness from 0,5 m to 20 m.

Linear gneiss of Iñaño

The next ridge further east of ½ to 1 km width, consists of a very pronounced linear gneiss, which eastwards changes into a planar gneiss. Its western boundary with the schists is sharp and is characterized by a greenish aphanitic rock, most probably a mylonite. The gneiss consists of rounded crystals of potassium feldspar, albite, undulose quartz aggregates and finely disseminated chloritized biotite.

Planar gneiss

The most typical planar gneisses are the muscovite gneisses between the above mentioned linear gneiss and the Pico de Meda granite gneiss. They are well exposed in the Rio de Barcia together with boudins of eclogite-amphibolites. The pronounced lineation plunges south. Potassium feldspar occurs as anhedral crystals between irregular plagioclase and cataclastic quartz.

Phengitic muscovite occurs in large, bent, often sheared crystals lying in the schistosity plane. The quartz crystals are often surrounded by cataclastic zones. Garnet crystals have been broken and replaced by clinozoisite and the stable combination of muscovite-epidote-clinozoisite is clearly of a later age than the garnets. Further constituents are biotite, zoisite, and locally amphibole. Accessories are titanite, rutile and orthite.

The granites and hornfelses

Granites occur in the muscovite gneisses and farther south in a badly exposed zone near Carballas. Within these granites muscovite gneisses occur sporadically associated with basic dykes.

In the Rio de Barcia augengneisses with big quartz augen are exposed marginal to the granite. A little farther north a new road-cut on the road Agualada-Puente Ceso shows a gradual transition from a somewhat sheared biotite granite to a gneiss. This transitional zone consists of a schistose granitic gneiss with feldspar augen. Biotite streaks surround these eyes with some recrystallized new biotite crystals.

These granites consist of large broken crystals of microcline perthite, saussuritized plagioclase, undulose quartzes, large bent biotites and some broken garnets.

Another badly exposed granite occurrence is found near Allones and some miles farther south near Cotaredo. In both places sharp contacts of the granite with hornfels have been observed. The hornfels consists of a fine granoblastic texture of brown pleochroitic biotite, polygonal quartz and cloudy plagioclase as poikilitic inclusions in relicts of a completely weathered unknown mineral, possibly originally cordierite. The rock contains further a little garnet, muscovite and many small magnetite crystals.

Hornblende gneiss

This rock occurs in one zone near the eastern border of the Central complex. Its schistosity is almost horizontal and slightly folded. Basic bands and lenses are conspicuously absent. The rock varies from an alternation of bands consisting of hornblende, biotite and reddish potash feldspar to a dark massive gneiss where the feldspar lies disseminated between dark minerals.

The mineral content is as follows: potassium feldspar, quartz, albite, ferro hastingsite [1], Fe-rich biotite, garnet, epidote, titanite, pyrite, apatite, zircon and ilmenite.

The leucocratic minerals occur as xenomorphous irregular crystals with undulose extinction. Biotite and ferro hastingsite occur also in cracks of the garnet crystals. Both minerals are of a rather late growth and the hornblende is locally replaced by biotite. Moreover the hornblende carries many inclusions of titanite, sometimes of garnet, whereby the garnet is restricted to the margin and the titanite to the core of the mineral.

Because this rock is much richer in alkali and Fe and Ti than the other gneisses or micaschists it is thought that it may represent an original plutonic or extrusive rock.

[1] This mineral has recently been investigated by professor Parga-Pondal and details concerning it will be published by him.

The micaschists

Micaschists, occurring in the Lage gneisses, in the Central complex and in the margins of the Basic complex are all very similar. In the Central complex feldspathic micaschists are linear and show microfolded s-planes. The schists between the Basic complex and the Meda zone of gneisses carry large garnet crystals and contain many microfolds and quartz rods parallel to the axis of these folds. The axial planes dip 50°—60° east, parallel to the schistosity of the frequently enclosed amphibolites. The lineation plunges 20°—30° to the south. A zone of graphitic schists can be followed intermittently from Beizana northwards to Malpica on the north coast.

The schists are characterized by a late growth of albite, quartz and mica. The schistosity bends round the albite porphyroblasts, which often contain a planar or slightly curved internal schistosity. Fig. 1. Garnet occurs partly as sheared and broken chloritized crystals, partly as small idioblasts.

The schists occur sometimes in a rapid alternation with planar leptinitic gneisses and streaks of augengneisses. These latter gneisses give then the impression to have originated by feldspathization of the micaschists.

Conclusions

Except for the Allones granite and perhaps the hornblende gneiss, all the rocks of the Central complex seem to represent a metamorphosed sedimentary series. The metamorphism has certainly a complex history, with an oldest synkinematic phase during which schistosities and lineations were made, a second phase with unoriented recrystallization partly destroying the earlier structures, another phase of deformation mainly folding the existing S-planes, which may be partly contemporaneous with the second phase, and finally a late shearing, responsible for the common cataclastic habit of many of the minerals.

THE PICO DE MEDA GROUP

The Pico de Meda group of rocks is rather similar to the Lage gneisses but they are generally of a finer grain and they are not tectonized by oblique shear zones as has been often observed in the Lage gneiss (and in the Borneiro augengneiss). Furthermore pegmatites are rare and basic rocks are absent. The group contains linear gneisses, augengneiss, granite gneiss, migmatite and granite with a few narrow schist streaks. The schistosity of the schists has been folded but in the gneisses this secondary folding escapes observation. The lineation plunges south with 10—30° and its strike shows a curve which is also expressed by the shape of the belt. Except the Buño fault all other dextral wrench faults of Parga's map had to be abandoned.

Although there is concordance of this belt with the surrounding rocks on a large scale, there is some discordance with the strike of the schists. The western contact with the schists in the Rio Allones is sharp and the contact is distinctly faulted.

Under the microscope it becomes evident that the finely laminated texture is due to a late shearing parallel with the axial planes of folded micas. These shear zones bend around late plagioclase porphyroblasts.

In the linear gneisses little is to be seen of strong deformation, probably due to postkinematic recrystallization. Various replacement features have been observed, for example potassium feldspar replaces plagioclase while forming myrmekite;

potassium feldspar is albitized along its crystal borders; replacement of feldspar by quartz along cracks and by quartz and muscovite (plumose mica) is common. Biotite and muscovite seem to occur in two generations, small crystals indicating the schistosity and arranged around the larger feldspar eyes, and large unoriented crystals, which show the effects of a late phase of shearing.

On the eastern side of the Pico de Meda gneiss belt near Agualada and west of the Basic rock complex occurs a region of rocks very similar to those of the Central complex. In this region an oval shaped body of migmatites alternating with gneisses with the same trend of schistosity as the surrounding schists occurs. The migmatites consist of a rapid alternation of leucocratic quartz-feldspathic bands and zones rich in mica and with augen and streaks of plagioclase.

These migmatites have a plastic flow appearance due to folded schistosity planes, which generally dip 15—55° to the E. Sometimes the feldspar bands are squeezed in the flanks and thickened in the hinges of these folds.

The fold axes plunge 25° south and are parallel to boudins of basic rocks. The latter rocks are locally feldspathized along their margins and transformed into hornblende gneiss or migmatite. These basic rocks contain rutile and have given rise to a few placer deposits.

These migmatites are characterized by a late growth of micas; the plagioclase (An 30) carries inclusions of mica and quartz. Garnet occurs as inclusions in biotite and as hollow crystals filled with biotite and quartz. The migmatites are probably produced by feldspathization of micaschists during late or postkinematic time, and were accompanied by plastic folding of the S-planes.

Other migmatites have been found along the Allones river; the rock types vary from banded migmatite to rather homogeneous porphyric granites of the La Ruña type, in which the feldspar megacrysts may be eyeshaped or euhedral. These crystals are either potassium feldspar or plagioclase (An 20). Albitization is not uncommon. Around the potassium feldspar megacrysts cataclastic borders of mica and quartz are commonly found. Biotite may be recrystallized in small unoriented crystals. Plumose mica occurs also in these rocks.

The Vari Longo granite, economically important by the occurrence of veins of tungsten, tin and arsenic ores, shows transitions towards the adjoining granite gneiss. The late mineralization is probably connected with a joint system striking NNE.

There can be little doubt that the Pico de Meda belt has been submitted to the same tectonic and metamorphic processes as the Central complex rocks. The minor structures as schistosities and lineations in both groups of rocks are parallel and very similar, both show a later phase of unoriented crystallization and a final phase of cataclastic deformation.

THE BAYO BIOTITE-GRANODIORITE

This rock occurs in a zone with a length of 50 km and a width of 1—5 km parallel to the regional trend of the Central complex and the Lage gneisses. Only the northernmost portion has been mapped. The granodiorite is a porphyritic rock with large plagioclase megacrysts, and often shows a distinct parallel structure due to parallelism of the megacrysts. The contact with the Borneiro gneiss is sharp, although schistose structures in both rocks run parallel. A few hundred metres from the contact disoriented xenoliths of augengneiss have been found and they indicate that at some time this rock has been in a very plastic or molten state. Farther south concordant xenoliths are present. Along the western border a few streaks of Lage gneiss are included in the granodiorite. Elsewhere the granodiorite is more or less migmatitic and less porphyric.

Microscopically the rock consists of plagioclase (An 27—50), quartz, potassium feldspar, biotite, green hornblende with zircon, apatite and ilmenite as accessories. Deformation of many of the minerals is again a common feature in these rocks.

THE BASIC COMPLEX

Amphibolites s.l.

In this category are included the schistose basic rocks of the Basic complex and those intercalated in the garnet-micaschists west of the Basic complex. The transition between both zones is gradual and the contact is concordant. Amphibolites occur also in the Lage schists west of the Central complex.

Petrographically this amphibolite group can be subdivided as follows:

A. 1) Epidote-amphibolites
   2) Epidote-zoisite-clinozoisite-amphibole rocks

B. 1) Plagioclase-amphibolites
   2) Plagioclase-amphibole rocks

Epidote-amphibolites. This subgroup varies from epidote-amphibolites to zoisite amphibole rocks. The rocks occur in the valley of the Rio de Noguera, which flows along the boundary of the Basic complex and in the northern extension of the complex near the Rio Allones. Epidote-amphibolites are finely schistose rocks with a parallel, linear arrangement of amphibole crystals. They change gradually into zoisite-amphibole rocks. Crystals of alpha-zoisite and clino-zoisite form white bands, eyes and veins in a dark amphibole mass. Linear amphiboles are scarce.

The unoriented rocks contain much, up to 8 mm long, lensshaped zoisite crystals. Their boundaries and those with amphibole are irregular. Locally amphibole has been replaced by zoisite, the latter including small crystals of amphibole showing straight extinction. The unoriented rocks have been formed during a period of static metamorphism.

Amphibole shows the following characteristics: Z is green-blue, Y is green, X is yellow-green, $Z/c = 16°$, $2V_X = 70°$. Amphibole with these properties occurs in nearly all rocks. Towards the outer margin pleochroism increases in intensity. Sometimes a colourless amphibole occurs in unoriented zoisite rich rocks, with the same or slightly larger optic axial angle. The green-blue amphibole sometimes shows ore concentrations in the center, which may render the mineral opaque; macroscopically it has then a dark metallic luster.

Epidote-clinozoisite occurs partly as individual, sometimes twinned grains between amphibole, partly as secondary crystals concentrated along shear zones and intergrown with plagioclase. The epidote may be concentrated in veins. Where epidote and amphibole are in contact, the marginally higher interference colours suggest a secondary formation of the former mineral.

Zoisite frequently occurs as alpha-zoisite and is then associated with amphibole. Zoisite and amphibole form irregular intergrowths and the latter is often included in the former.

Plagioclase is present as polygonal crystals with quartz and clinozoisite. It also occurs as saussuritized remnants in zoisite. The anorthite content varies from

20—25. The small untwinned crystals do not facilitate measurements; all anorthite determinations in the basic rocks were done on untwinned crystals by the method of Fouqué.

Titanite is typical for the amphibolites, taking the place of rutile. Locally ilmenite and pyrite occur. Clinochlore, prehnite, sericite and carbonate are minerals of the latest stages of the static retrograde metamorphism.

Plagioclase amphibolites s.l. — On structural grounds this group can be divided as follows:

(1) plagioclase-amphibolites s.s.,
(2) unoriented plagioclase-amphibole rocks.

It is often difficult to distinguish between both types. Transition from one to the other may either be gradual or sudden, and are often masked by dynamo metamorphic influences. It seems likely that in the Basic complex from west to east epidote-amphibolites s.l. change via plagioclase-amphibolites s.l. into epidiorites. The latter can, however, also be intrusive in the amphibolites. It has been noticed that in the Basic complex the epidote-titanite percentage decreases from west to east, that plagioclase and ilmenite increase, and that unoriented textures increase also. Statically recrystallized plagioclase-amphibolites occur at the western side of the garnet-micaschists along the gneiss contact. Linear plagioclase-amphibolites contain plagioclase porphyroblasts which distinguish them from plagioclase-amphibolites with granoblastic plagioclase. The latter present themselves as banded, schistose rocks on the west side of the Central complex and also as linear plagioclase-amphibolites in the schists east of Monte Perrol. They occur in the schists west of the Basic complex, especially in the Rio Rodis zone and SE of Brenlla. The plagioclase porphyroblasts have partly oriented, partly random inclusions of epidote, amphibole and ore. The oriented ones represent relicts of a former schistosity, which is not otherwise apparent in the thin sections. Amphibole forms nematoblastic crystals parallel to the tectonic b-axis. The relict schistosity has been preserved as helicitic inclusions in epidote crystals, which often have been rotated. The same kind of structures occur in albites of the Rio Rodis zone. Relicts of more basic plagioclase, sometimes showing straight extinction, are found in and adjacent to the albite porphyroblasts. This indicates albitization of the original oligoclase. These porphyroblasts are frequent in basic intercalations in the schists SE of Brenlla. In one sample the linear amphiboles are bent around statically formed porphyroblasts or they pass straight into them. In other samples epidote inclusions show a relict schistosity which has been rotated. The epidote inclusions can, however, also occur unoriented.

The eclogite-amphibolites

As such is defined a type of rock with a mineral association of garnet, pyroxene and rutile which as a result of dynamic and retrograde metamorphism is gradually transformed into a garnet-amphibole rock.

As primary minerals these rocks contain: garnet, pyroxene, and rutile, zoisite, quartz and sometimes muscovite, kyanite and plagioclase. Secondary minerals are: amphibole, clinozoisite-epidote, zoisite, ilmenite and titanite.

The eclogite-amphibolites occur as follows:

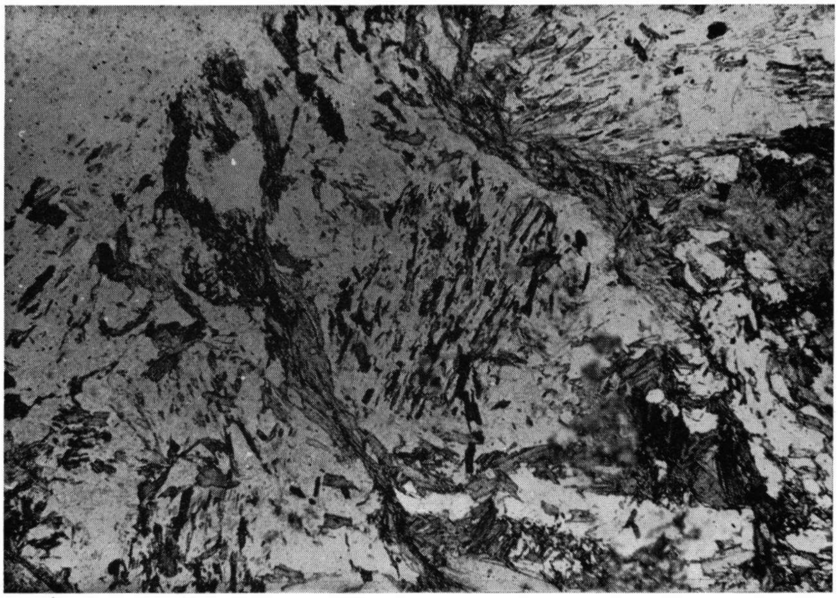


Fig. 1. Feldspathic schist from Sierra de Borneiro. Albite porphyroblast with internal s, making angle with se.

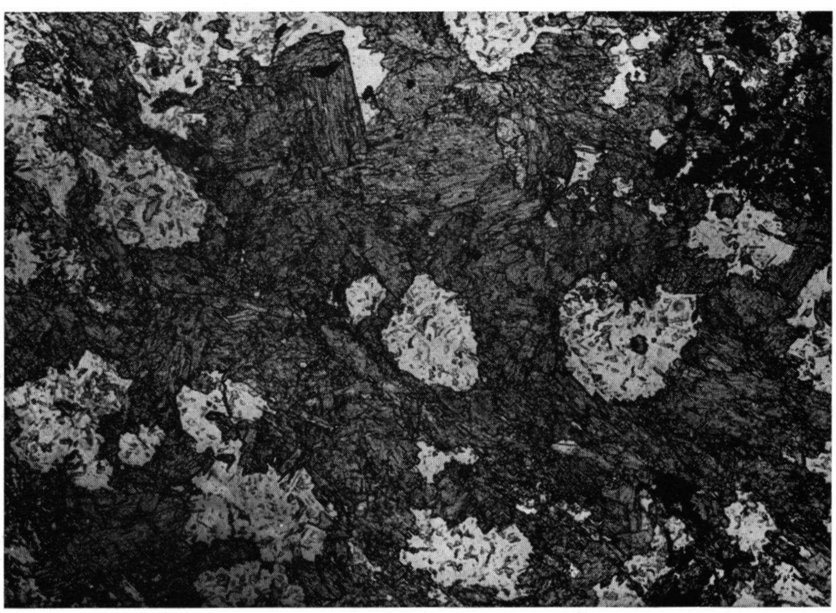


Fig. 2. Plagioclase-amphibole rock from Sierra de Borneiro.

(1) along the zone of granites of the Central complex, especially to the east in the muscovite-gneisses (valley of the Rio de Barcia),
(2) some other occurrences in this complex near Cesullas and Cotaredo,
(3) along the boundaries of the migmatite zone of the Pico de Meda group and the Basic complex near Brenlla, Ferreira and in the valley of the Rio de Rodis.

Garnet partly forms small idioblasts between the pyroxenes. The original texture was granoblastic, this is now masked by the effect of later amphibolitization. In the last mentioned occurrences of these rocks (3) crystals of ca. 1 mm size occur which contain primary inclusions of small pyroxene crystals. Secondary inclusions are finally dispersed rutile crystals which have partly recrystallized in veins through and around the corroded garnet. Other secondary inclusions are: amphibole, clinozoisite, plagioclase and quartz. Fig. 3 and 4.

Pyroxene occurs as small elongated and oriented crystals and as larger unoriented crystals. This orientation is visible in thin sections perpendicular to the tectonic b-axis. The mineral has a low birefringence (0.015), is occasionally pleochroic (lightgreen) and shows locally a strong dispersion; $Z/c = 40°$, $2V_Z = 70°$. It is probably a sodium bearing pyroxene. The occurrence of symplectitic intergrowth with plagioclase near Brenlla also points in this direction.

Rutile occurs partly as primary anhedral crystals, partly as small secondary crystals included in garnet.

Plagioclase (An 25—26) has been found in a few rocks as symplectitic intergrowths with pyroxene.

Zoisite occurs in varying quantities either as long prismatic, parallel oriented crystals in garnet-amphibole-plagioclase rocks of the Central complex, or as small unoriented prisms. The first mentioned crystals can be regarded as relicts from the eclogitic stage and are in any case older than the amphibole. The second group of the zoisite crystals occurs in clusters and is probably derived from pyroxene and garnet. Especially pyroxene is scarce in zoisite-rich parts; β-zoisite is dominant.

Muscovite and quartz occur locally between the other constituents. The crystals have not been deformed and this general outlook makes it probable that muscovite and quartz should be regarded as primary contituents of the rock.

Kyanite has been found in one specimen of the Rio Rodis and will be discussed later on.

The characteristic primary mineral association to which the eclogite-amphibolites can be related consists of garnet, pyroxene and rutile. The mineral paragenesis of the eclogite facies is omphacite, Ca-magnesium-rich garnet and rutile. Furthermore kyanite and zoisite are characteristic for the eclogite facies. Further mineralogical investigation will have to prove whether the garnet and pyroxene are of such composition as to be characteristic for true eclogites.

The secondary association is mainly typified by amphibole. It is the dominant mineral in most of the eclogite-amphibolites. It contains many poikilitic inclusions of garnet and zoisite and to a minor degree also of corroded pyroxene and is clearly a secondary mineral. The process of amphibolitization can be seen in the eclogite-amphibolite boudins in the Rio Barcia. These boudins are jointed and along these joints numerous unoriented amphibole crystals are found. These crystals may reach a size up to 1 cm and do not occur in the central parts of the boudins, or at least they are scarce there. The country rock is a planar muscovite-epidote gneiss with deformed and altered garnets. The gneiss shows a lineation parallel to the regional trend. The boudins have their long axis parallel to this B-axis. In one specimen the

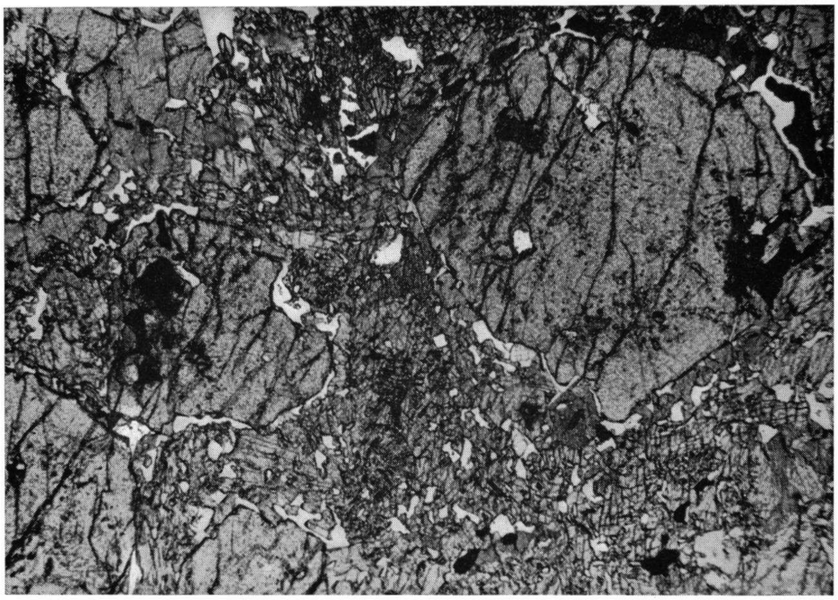


Fig. 3. Eclogite-amphibolite, near Brenlla. Large garnets in matrix of pyroxene, amphibole and plagioclase.

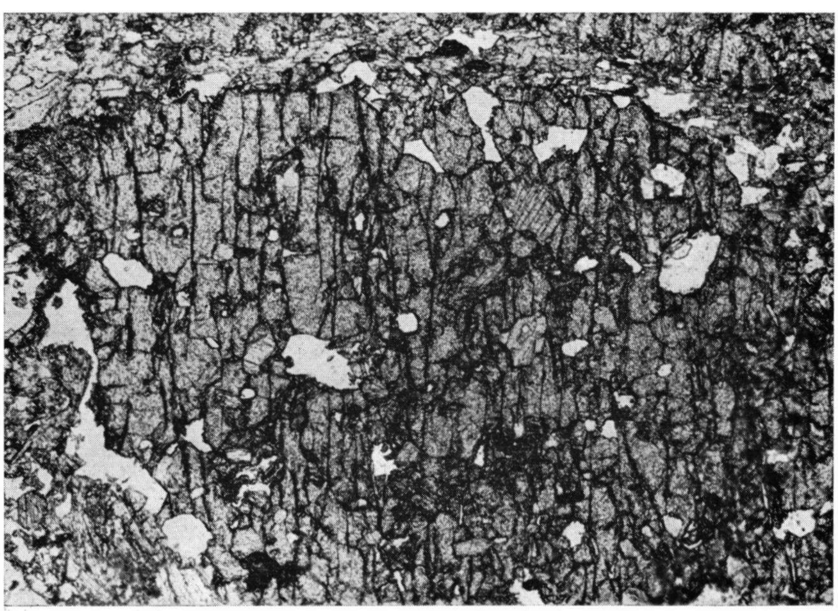


Fig. 4. Eclogite-amphibolite, near Ferreira. Garnet with inclusions of pyroxene, amphibole and plagioclase.

parallel lineation is determined by the arrangement of the amphiboles, which gives the rock a striped outlook; in general, however, the amphiboles do not show a preferred orientation. Probably the amphibolitization started in a synkinematic or late-kinematic stage since there is some connection between the formation of the boudins and this process. Amphibole also occurs as a fine, fibrous rim around pyroxene crystals; in some cases the pyroxene has been completely replaced by this fibrous amphibole.

Most of the blue-green and greenish-blue amphiboles occur along the margin of the crystals and are rather late grown. Lightgreen and brownish-green amphibole is found in rocks of the migmatite zones of Agualada. Green pleochroism is typical for many amphibolites. Colourless tremolitic to actinolitic amphibole is also common and always forms unoriented crystals.

These later stages of alteration of the eclogite-amphibolites can be studied in an outcrop on the southside of the Rio Barcia, where coarse grained veins and masses of clinozoisite-amphibole-chlorite occur in these rocks. Amphibole porphyroblasts contain inclusions of corroded pyroxene relicts, zoisite rods and somewhat altered garnet. The latter mineral is often rounded, lacks its idioblastic form and is often altered into clinozoisite and chlorite. Some muscovite crystals have been formed late as evident by the garnet, pyroxene and zoisite inclusions. In lower metamorphic stages pyroxene is not found, the amphibole is fibrous or lamellar. Garnet inclusions are absent or have been altered into clinozoisite, chlorite and sometimes albite. Most probably this amphibole is of the tremolite type, with marginal transformation into chlorite and albite, the same type as occurs in the joints. Rutile has been altered into titanite. Sometimes ilmenite has titanite rims. Finally a clinochlore-tremolite rock is formed with little clinozoisite and no relict minerals.

The basic rocks of the migmatite zone near Agualada

Garnet-hornblende rocks occur as boudins in migmatites. Sometimes the outer part of these boudins has been feldspathized. The long axis of the boudins is parallel to the tectonic b-axis. In N-S sections the basic rocks appear as lenses in one horizon. In one case such a lens occurs as a discordant body in the country rock, which shows a mylonitic structure as a result of strong shearing; the basic rock shows a blasto-mylonitic structure. Macroscopically a fine lineation of ca. 3 mm long amphibole crystals can be seen, microscopically the rocks show no orientation. Apart from amphibole, garnet can sometimes be recognized macroscopically. The crystals of about 0.8 mm size exhibit an atol structure similar to the garnets known from the enclosing mica-rich migmatite.

Amphibole forms porphyroblasts with inclusions of garnet, plagioclase and sometimes pyroxene. The pleochroism, characteristic for all amphiboles of the migmatite zone, is dirty green to lightbrown. $Z/c = 16—18°$, $2V_X = 80°$. Amphibole has been formed later than rutile, garnet and pyroxene. Thus these rocks are probably derived from eclogite-amphibolites. The uniform pleochroism of the amphibole in both rock types also seems to indicate this.

Garnet forms poikilitic inclusions in the amphibole. Fig. 5.

Plagioclase is present in granoblastic, frequently zoned crystals (An 27), often with round quartz inclusions. The plagioclase which has been formed later than the amphibole occurs in this mineral as vermicular inclusions, or grows in the cleavages of this mineral. Exceptionally a similar intergrowth with biotite has been observed.

Clinopyroxene occurs as individual crystals with a wavy extinction and as symplectitic intergrowths with amphibole. Pyroxene clearly forms unstable relicts between the amphibole crystals.

Rutile and also ilmenite have been marginally altered into titanite. Rutile may occur as individual crystals or as inclusions in the garnet.

The garnet-hornblende rocks are statically recrystallized eclogite-amphibolite with poikiloblastic texture, metamorphosed in the lower part of the amphibolite facies.

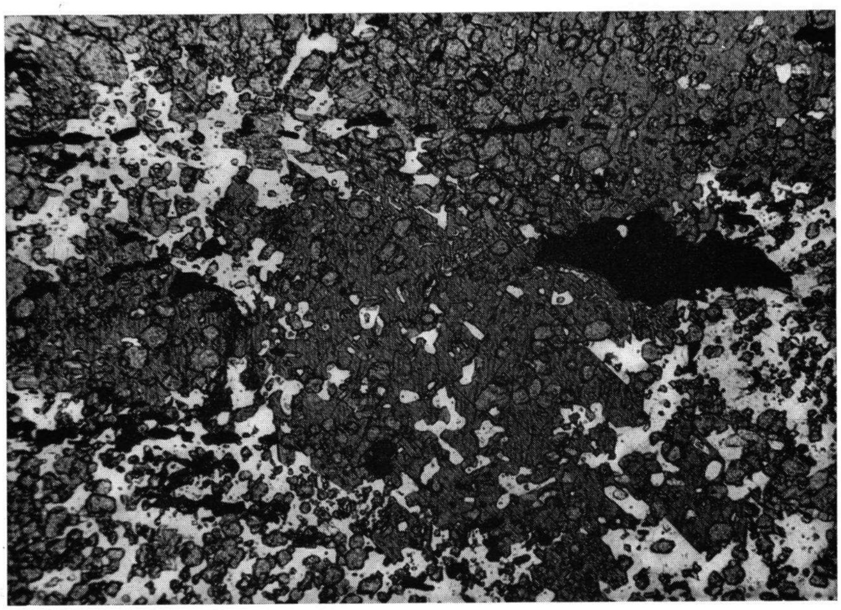


Fig. 5. Garnet-amphibole rock, near Agualada. Small garnets in large amphibole crystals.

Hornblende migmatites

Their occurrence at the margin of the garnet amphibole rockzone has already been mentioned. It seems clear that the feldspathization is related to the migmatization process. However, not all boudins have been feldspathized.

The hornblende migmatites themselves are banded gneissose rocks and rather homogeneous. The oriented structure is due to deformation as evident by the cataclastic fine-grained amphibole and biotite bent round the boudins. In the more homogeneous migmatites we see unoriented equidimensional amphiboles and euhedral plagioclase. Microscopically the texture is cataclastic and similar to the texture of the gneisses of the Central complex. The larger crystals show sheared rims and wavy extinction.

Amphibole is not porphyroblastic and has irregular boundaries.

Garnet is often completely altered into clinozoisite and chlorite, locally crushed, with biotite in the fissures.

Plagioclase contains sporadic round quartz inclusions and also small inclusions of potassium feldspar. This mineral also occurs in sericitic veins and masses in the oligoclase.

Biotite is often chloritized. Titanite and ilmenite occur instead of rutile.

On the west side of the migmatite zone (Rio Rodis) a small outcrop of kyanite bearing eclogite-amphibolite has been found. The rock contains: garnet, rutile, zoisite, symplectitic intergrowth of pyroxene and plagioclase, amphibole and quartz. Kyanite occurs between these minerals and shows characteristic alteration rims. It is also present in long, strongly undulose crystals in a segregation vein. The presence of kyanite may indicate high pressure.

In the Rio Rodis valley occur different basic rocks as epidote amphibolites, and chlorite and talcum-rich rocks.

The garnet amphibole rocks of the Central complex

These include al those basic rocks of the Central complex whose derivation from eclogite amphibolites can be traced through several successive stages. This large group can texturally be distinguished in cataclastic-mylonitic, blasto-mylonitic rocks and completely recrystallised metadioritic rocks. Mylonitic textures occur in the granite zone and along the eastern boundary of the complex. They are related to fault zones. As a result of later recrystallization mylonitic textures gradually become blasto-mylonitic. Blasto-mylonites occur in the feldspar bearing schists and the linear gneisses of the Central complex (Sierra de Borneiro). Static metamorphism was strongest in the linear gneisses, as is evidenced by the recrystallization which can be observed in these gneisses.

Mineralogically the blasto-mylonites can be subdivided into plagioclase-amphibole rocks Fig. 2. and garnet-clino-zoisite-amphibole rocks. Other constituents are: biotite, zoisite, quartz, chlorite and epidote, which occur in various quantities. Accessories are: ilmenite, titanite, pyrite and apatite.

The mylonites contain relicts of garnet, rutile and locally pyroxene. The latter exhibiting the dispersion typical for pyroxenes of eclogite-amphibolites. Alteration products are: clinozoisite, biotite, chlorite, amphibole, ilmenite and titanite. Muscovite, biotite, plagioclase and quartz formed in veins parallel to the shearing direction are of relatively late stage.

Characteristic for the mylonites is a nearly opaque amphibole, occurring as fine, parallel fibres and formed from pyroxene. Broken and crushed garnets are diagnostic for the blasto-mylonites. After the deformation of the garnet unoriented growth of amphibole (pleochroism from colourless to lightgreen, $Z/c = 15°$, $2V_X = 80°$), biotite, clinozoisite and plagioclase took place.

Plagioclase occurs as static albite porphyroblasts with small unoriented inclusions of corroded garnet, amphibole, quartz, clinozoisite and titanite, and also as thin albite rims around zoisite. Plagioclase and amphibole both may show zonal structure, as evidenced by zonal extinction and blue-green rims. Zoisite occurs in porphyroblastic crystals and elongated masses (Sierra de Borneiro). Macroscopically it is visible as white elongated, irregular crystals parallel to the orientation of the country rock. Under the microscope it appears as long, parallel crystals, forming bands along garnet and amphibole. Unlike in the eclogite-amphibolites there are no inclusions of zoisite in the amphiboles.

Biotite formed probably already in cracks in the garnet crystals as it is now found as bent crystals in the clinozoisite. The alteration of garnet into clinozoisite is also characteristic for some blastomylonites of the Central complex. Locally amphibole also forms inclusions in the clinozoisite porphyroblasts. Albite and chlorite belong to the last minerals formed by static, retrograde metamorphism and occur in minor quantities.

The sequence of mineralization is as follows:

(1) fibrous amphibole from pyroxene and garnet, ilmenite from rutile;
(2) biotite in cracks in garnet and from fibrous amphibole; zoisite from garnet and fibrous amphibole, probably concentrated in old shear zones; colourless amphibole (probably actinolite-tremolite) between deformed garnet and from fibrous amphibole; titanite from ilmenite.
(3) clinozoisite from garnet; epidote locally in tension cracks; oligoclase concentrated around and between deformed garnet.
(4) albite and chlorite from clinozoisite, biotite and amphibole.

The adjoining geologic map shows all basic rocks types that have been examined petrographically. It is concluded that the basic rocks of the Central complex were originally eclogites which passed through several retrograde metamorphic stages that first produced blastomylonites and subsequently recrystallized into metadioritic rocks. It is suggested therefore that the Central complex is typified by a presently incompletely understood sequence of metamorphic events which point to initially high grade metamorphism and P-T conditions relative to a deepseated position within the earthcrust.

Evidence of a strongly faulted eastern margin of the Central complex was found while other zones of shear and mylonitization also occur within this complex itself. The eastern Meda zone, although exhibiting the same structural features as the Central complex, contains the relict high grade facies conditions in the Agualada zone of migmatites only. The characteristic metamorphic assemblage is here of medium grade (epidote-amphibolite facies to amphibolite facies).

THE IGNEOUS ROCKS OF THE BASIC COMPLEX

Gabbro's and metagabbro's

Outside the mapped area olivine gabbro's have been found at the Monte Castello, which have been compared with those occurring in the Basic complex. Going west from the Monte Castello first gabbro's and norites are found and then amphibolites with a NW strike and a dip of 35° to the NE. Unfortunately the contact is not very well exposed. A few tens of metres from the amphibolites metagabbro's with serpentine, talcum, uralite and zoisite are exposed. The amphibolites consist of oriented amphibole, epidote, quartz and albite. The amphibole has a dark bluish-green pleochroism. It seems likely that the gabbro's are intrusive in the amphibolites and that both subsequently have been metamorphosed in the epizone.

East of the Monte Castello metagabbro's, epidiorites and cordierite- spinel-sillimanite-garnet-plagioclase felses are exposed. They will not be discussed here. NE of this hill occur metagabbro's, epidiorites and amphibolites with ophitic relict textures.

Petrographically the following types of gabbro can be distinguished: (1) olivine-gabbro's and norites, (2) hypersthenegabbro's and norites, (3) hornblende-gabbro's.

The microscopic textures are ophitic or hypidiomorphic.

The following alterations have been observed:

pyroxene to bastite, colourless fibrous amphibole Cummingtonite?) and lightgreen amphibole, chlorite, zoisite-clinozoisite, talcum and serpentine;

olivine to iddingsite, talcum, ore and serpentine;
plagioclase to sericite, saussurite, clinochlore;
brown hornblende to fibrous amphibole.

Many of the alterations are pseudomorphs and therefore the igneous textures are well preserved.

Garnetiferous gabbro's

In these rocks garnet occurs as reaction rims between plagioclase (andesine-labradorite) and pyroxene which often are strongly bent. After the formation of these rims several alterations took place: garnet is replaced by epidote-clinozoisite and chlorite; brown-green hornblende is formed at the expense of pyroxene and is at its turn replaced by bluish-green amphibole; plagioclase is albitized and altered into clinozoisite; ilmenite is altered to titanite. Fig. 7.

The final result is a plagioclase-quartz-clinozoisite-amphibole rock which cannot macroscopically be distinguished from the epidote-amphibole-rocks. It is remarkable, however, that the original ophitic texture often is well preserved. It is supposed here that these rocks intruded under synkinematic circumstances, followed by a later phase of retrogressive and static metamorphism.

Epidiorites

Epidiorites are plagioclase-amphibole rocks with a clear subophitic relict texture. They change gradually into amphibolites and plagioclase-epidote-amphibole rocks without relict textures. The anorthite content of the plagioclase of these rocks is higher than that of the amphibolites s.l. It varies from 30—55 %. The twins are typical for igneous rocks. Amphibole occurs as green fibrous to granoblastic crystals, pseudomorphous after pyroxene. Sometimes a reaction rim exist between amphibole and plagioclase consisting of clinozoisite-zoisite.

Ilmenite occurs accessory; it may be a little altered to leucoxene and titanite.

Conclusions

The examination of the gabbroic rocks of the Basic complex has shown that they are late and post-kinematic and postmetamorphic intrusive rocks. The sub-division is based on the occurrence of garnetiferous gabbro's, saussurite-gabbro's and entirely fresh gabbro's.

ULTRABASIC ROCKS

Peridotites occur as a concordant body along the eastern border of the migmatite zone near Agualada and as a zone of ultrabasic dykes, lenses and masses along the border of the Basic complex from the Nogueira valley to the Rio Allones. The most important body is that of Coton de Ferreira. East of Agualada the peridotite zone forms the eastern boundary of the occurrence of garnet in basic rocks.

Macroscopically the ultrabasic rocks are massive rocks or show a fine banding. Serpentinization is visible in many outcrops.

Fig. 6. Olivine-gabbro, Monte Castelo.

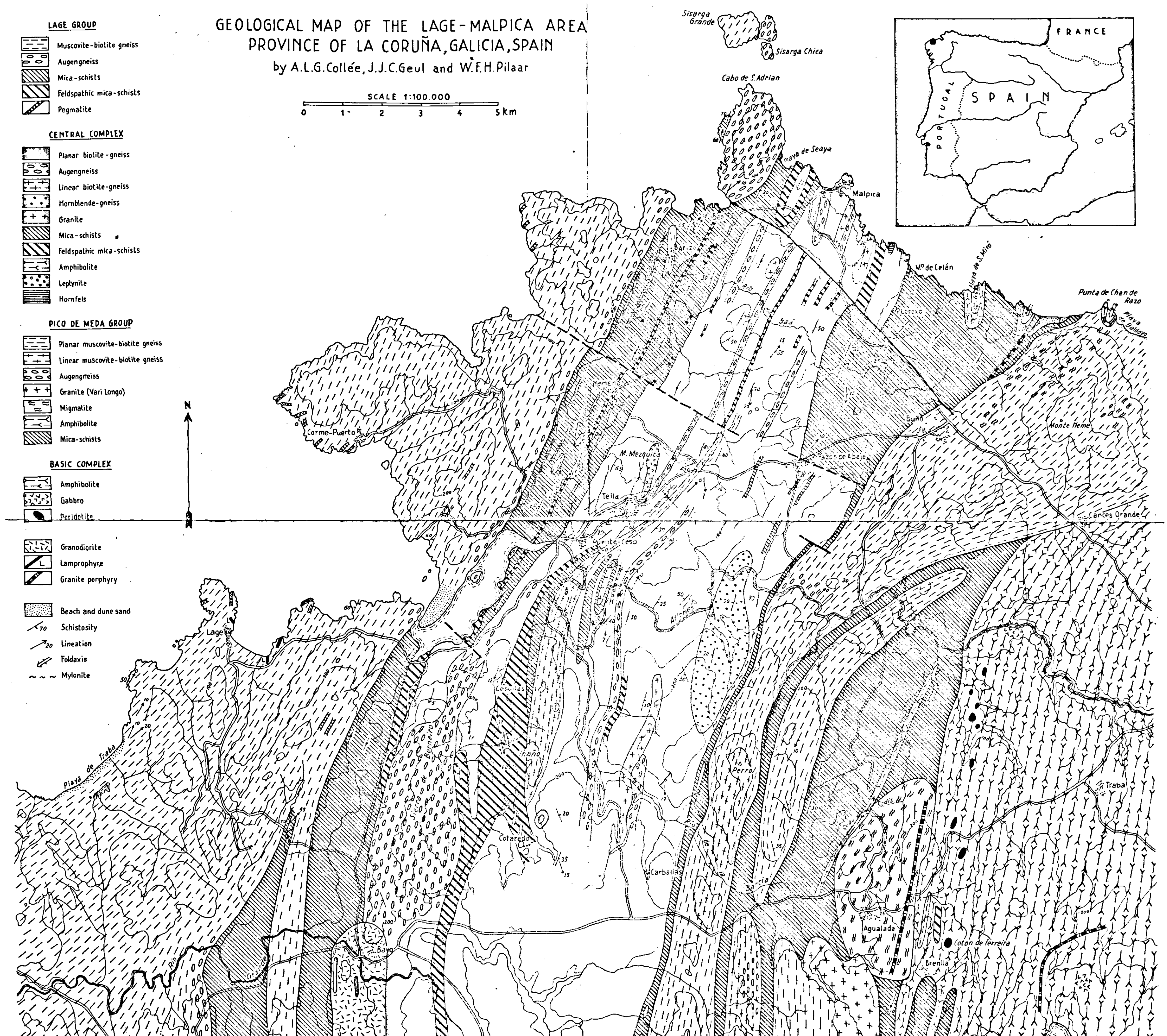
Fig. 7. Garnetbearing meta-gabbro, near Agualada. Reaction rims of garnet around plagioclase.

The following minerals have been observed: olivine, chrysotile, antigorite, enstatite, clinopyroxene, bastite and tremolite, chromium-bearing chlorite (kotschubeite and kämmerite), picotite magnetite, pyrite and magnesite.

The peridotite of Coton de Ferreira has a banded, mylonitic structure; ore bands alternating with bands of cataclastic olivine. Also enstatite often is strongly deformed.

GREENSCHISTS AND GREENSTONES

In shearzones along the border of the peridotite zone and a few hundreds of metres from the Basic complex greenschists and greenstones occur. Megascopically they are green, unoriented to weakly oriented rocks. Microscopically they can be divided in two groups. The occurrences near Rio de Nogueira are derived from pyroxenites, as visible by the partly altered clinopyroxenes and orthopyroxenes into tremolite, clinochlore and ore. They belong to the ultrabasic zone. The outcrops just south of the Rio Allones are probably associated with serpentinites. They contain some relict pyroxene in a tremolite mass. Further constituents are clinochlore, clinozoisite-zoisite and titanite.


GEOLOGICAL MAP OF THE LAGE-MALPICA AREA
PROVINCE OF LA CORUÑA, GALICIA, SPAIN
by A.L.G. Collée, J.J.C. Geul and W.F.H. Pilaar
SCALE 1:100.000
0 1 2 3 4 5 km
LAGE GROUP
Muscovite-biotite gneiss
Augengneiss
Mica-schists
Feldspathic mica-schists
Pegmatite
CENTRAL COMPLEX
Planar biotite-gneiss
Augengneiss
Linear biotite-gneiss
Hornblende-gneiss
Granite
Mica-schists
Feldspathic mica-schists
Amphibolite
Leptynite
Hornfels
PICO DE MEDA GROUP
Planar muscovite-biotite gneiss
Linear muscovite-biotite gneiss
Augengneiss
Granite (Vari Longo)
Migmatite
Amphibolite
Mica-schists
BASIC COMPLEX
Amphibolite
Gabbro
Peridotite
Granodiorite
Lamprophyre
Granite porphyry
Beach and dune sand
Schistosity
Lineation
Foldaxis
Mylonite
N
FRANCE
SPAIN
PORTUGAL
Sisarga Grande
Sisarga Chica
Cabo de S. Adrian
Playa de Seaya
Malpica
Mº de Celán
Punta de Chan de Razo
Corme-Puerto
M. Mezquita
Tella
Suño
Monte Neme
Cances Grande
Puente-Ceso
Lage
Playa de Traba
Cotaredo
Carballas
Perrol
Traba
Agualada
Coton de ferreira
Brenlla
Bayo