THE GEOLOGY OF THE COASTAL SECTION FROM CABO DE SAN ADRIAN TO PLAYA DE BALDAYO

(GALICIA)

BY

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INTRODUCTION

During the field season of 1956 and 1957, an area in the NW part of the province la La Coruña was investigated. On the north the area is bounded by the Atlantic ocean, its southern boundary is formed by the roads: Beo-Malpica and Malpica-Buño. The Monte Neme forms the eastern limit of the mapped area. Formerly this area has been studied by Professor I. Parga-Pondal and L. T. Schoon. The results of these investigations served as a basis for this study.

Along the coast a well exposed complete cross section through the Central complex can be studied. A part of the Lage formation is exposed at the ends of the cross section, viz. the augengneisses of the Cabo de San Adrian in the west and the migmatites of the Monte Neme in the east. Special attention has been paid to the basic intercalations, which frequently occur in the rocks of the Central complex. The characteristics of these intercalations served to elucidate the metamorphic history of the region. Their sensitivity to changes in temperature and pressure make them a much better metamorphic indicator, especially in microscopic study, than the acid rocks. The mineralogical composition of the latter is hardly affected by metamorphism; its main influence being apparent in structural changes of these rocks.

From west to east, the area investigated can be divided into three parts:

1. the augengneisses of Cabo de San Adrian; a lenticular body of gneisses and granites belonging to the Lage formation, surrounded by andalusite bearing two-mica schists.
2. The central part, showing a rather complete cross section through the Central complex; it can be subdivided into two parts:
   a. The western part, running from the Seaya Beach to Molinos de Celan, which is almost entirely composed of various gneissic rocks, with garnet bearing two-mica schists at thè top. Basic intercalations are frequent.
   b. The eastern part, from Molinos de Celan to the Punta de Chan de Razo, where the so-called Buño series occurs. It consists of gneisses, epidote amphibolites and garnet bearing two-mica schists. The series is folded into several successive anticlines.

   The transition between these two parts of the Central complex is very abrupt, probably due to strike faulting; this could however not be proved in the field.
3. The Monte Neme, belonging to the so called Meda group, a subdivision of the Lage formation, is a badly exposed Tungsten-tin bearing granite, surrounded by a migmatite zone, gradually passing into garnet bearing two-mica schists.

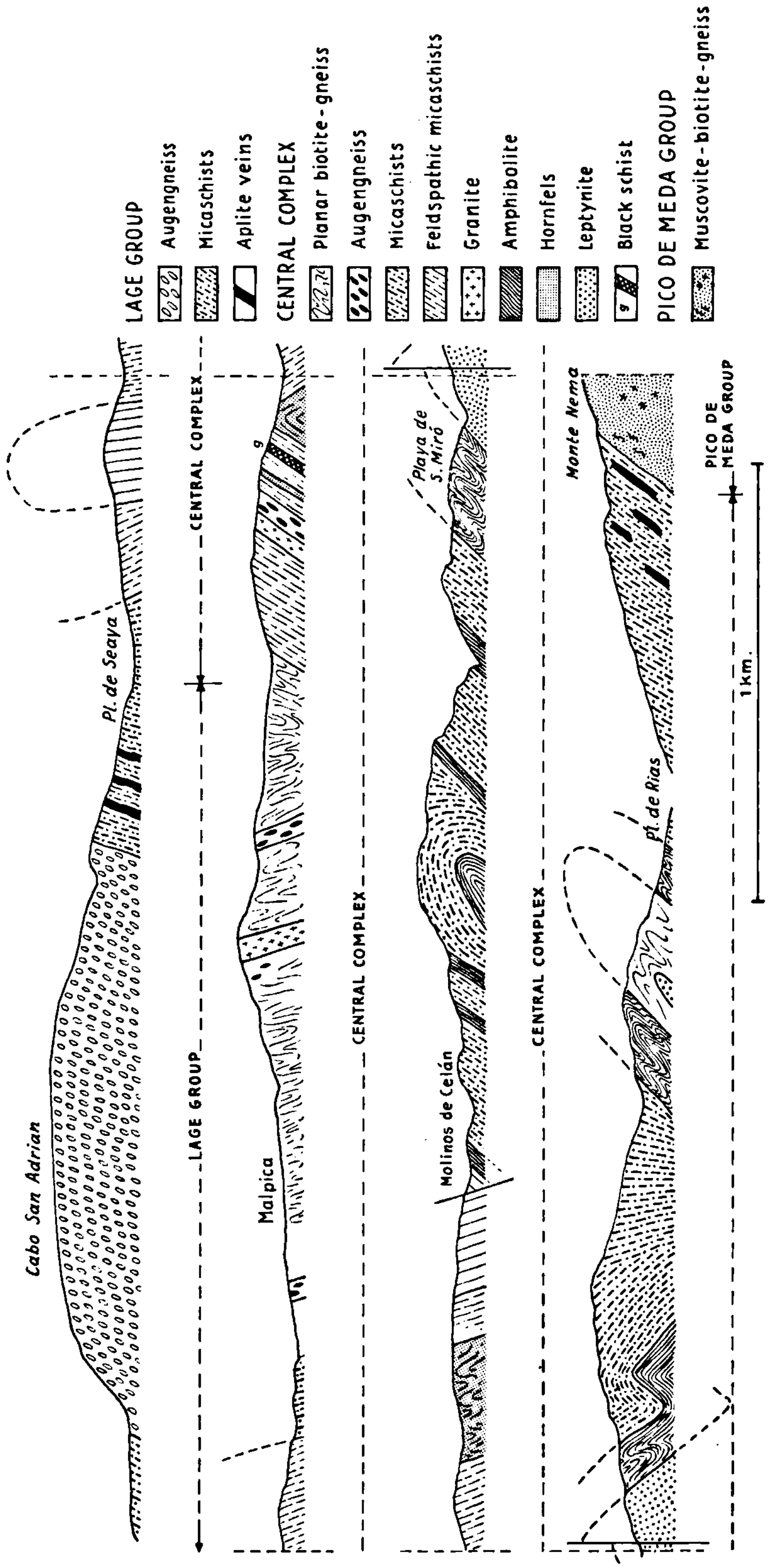

Fig. 1. Coastal section from Cabo de San Adrian to Monte Neme.

THE GNEISSES OF THE CENTRAL COMPLEX

Introduction

Gneisses occur mainly in the western part of the cross section through the Central complex, between the Seaya Beach and Molinos de Celan. In the east they are only found in anticlinal cores. In the field as well as microscopically one can distinguish three types of gneissic rocks:

1. Gneisses s.s.
   a. Augengneisses.
   b. Recrystallized gneisses.
   c. Leptynites.
2. Granites.
3. Gneissic schists.

The gneisses s.s. are by far the most abundant. The gneissic schists form a transition between the gneisses s.s. and the schists. They grade into each other as can be observed in the anticline west of Malpica.

The gneisses s.s.

Augengneisses are rare, they occur in bands parallel to the strike, mainly east of Malpica. They are characterized by strongly deformed microclines. In composition they are similar to the other gneisses: quartz, albite and microcline are the principal constituents, accessory minerals are garnet, epidote-clinozoisite, biotite (mostly altered to chlorite), muscovite and sphene. The augenstructure of these rocks is chiefly a macroscopical feature. Under the microscope it is less distinct, due to strong recrystallization. Therefore the recrystallized gneisses, are thought to have originated, from the augengneisses by a process of static recrystallization. The strong banding observed in the hand specimens also is only a macroscopical feature. It has been observed in thin sections that recrystallization altered these rocks into a chaotic mass of intermingled crystals of quartz, microcline and albite. Yet sometimes there are indications of an earlier existing augenstructure: bent micas form a rim round a mass of quartz and albite with in its centre a microcline crystal.

Locally the gneisses contain much quartz. These leptynites are readily recognized in the field by their concentric folding, in contrast with the other gneisses which show shear folding. As could be observed at the Monte Atalaya and at the San Miro Beach, the leptynites form a distinct horizon within the gneisses of the Central complex. This is thought to be an argument for their sedimentary origin. All gneisses contain numerous basic intercalations, that will be dealt with later on.

The granites

The genesis of the granites is an unsolved problem. In two bands, parallel to the strike between Malpica and Molinos de Celan, granitic rocks occur. They are coarse grained, with only a faint schistosity. In thin sections no parallel orientation of the constituents is discernable. Their mineral content is almost the same as that of the gneisses s.s., except for the plagioclase which has a somewhat higher Ca content (oligoclase). The alteration of microcline into albite, a characteristic feature of the gneisses s.s. is also discernable in the granites, though much less pronounced.

The granites too, contain basic intercalations, of eclogite and epidote-amphibolite. Locally the granite is affected by post metamorphic shearing, a feature frequently observed in all the rocks composing of the Central complex. The effect of this shearing locally makes the granite resemble strongly the gneisses s.s. No direct contact metamorphism was observed along the granites, but rocks that could be considered as hornfelses occur east of one of the granites, with an interval of several hundreds of meters between them. Their genetic relationship could not be proved.

Gneissic schists

These rocks form a transition between schists and gneisses. Their occurrence is limited to the western part of the Central complex, where no thick horizon of basic rocks separates the gneisses and schists. They are well developed west of Malpica and show a more pronounced schistosity than the gneisses s.s., but augen structures are absent. Gneissic schists are also found in the neighbourhood of the granites. In contrast with the gneisses s.s. the gneissic schists contain hardly any microcline.

SCHISTS

Except one occurrence of black schists, all schists of the Central complex are muscovite-schists with a low biotite content. They form a well determined horizon on top of the gneisses, separated from them by basic rocks in the eastern part and by gneissic schists in the western part of the Central complex. Within the schists basic intercalations also occur, but they are less frequent than in the gneisses.

The principal constituents of the schists are faintly coloured mica, quartz and generally some biotite and garnet. Tourmaline, apatite and sphene occur as accessories. Some schists contain Ca-rich minerals like epidote and clino-zoisite, in such a case it is difficult to distinguish them from the derivates of the basic rocks.

The schists have an intensely folded schistosity. A minor part of the micas is of post-kinematic origin, as is proved by their oblique orientation in relation to the folded schistosity. Albite porphyroblasts, frequently occurring in the gneisses are also found in the schists. Due to an even later period of shearing, they have rotated, and have augen shaped forms.

The Lage schists of the Monte Neme and the Cabo San Adrian, have a higher degree of metamorphism as is proved by the occurrence of andalusite and their higher biotite content.

BASIC ROCKS

Introduction

Five different types of basic rocks can be distinguished:

1. Amphibole bearing eclogites
2. Amphibolites
3. Epidote-amphibolites
4. Chlorite-albite rocks
5. Jadeite-glaucophane-garnet rocks.

They occur as concordant sheets, or as boudins in the country rock, showing great variation in thickness (from a few centimetres to tens of metres) and in frequency of occurrence. They are abundant in the gneisses, and form a thick layer between the gneisses and the schists in the eastern part of the Central complex. Within the schists these rocks are relatively rare, they are missing in the Lage formation.

The folding of the basic rocks is sometimes concentric, but the more schistose types show shear folding. In the gneisses, basic rocks frequently occur as boudins.

The very sharp boundaries of the basic rocks might indicate a magmatic origin, and the limitation of their occurrence in horizontal and vertical direction could be interpreted as an indication for their initial magmatic origin.

Amphibole bearing eclogites

The only exposure of this rock type was found in the granite. The contact between the two could not be observed. The eclogite is a medium grained rock, with a vaguely parallel orientation of its constituents. It is composed of: garnet, clinopyroxene, rutile, with some quartz and mica. Pyroxene alters to amphibole, garnet to epidote-clinozoisite, and rutile to sphene.

An attempt was made to determine the clinopyroxene. The following data were obtained:

Z/c 16 measurements, mean 39,8°, variation 30—50°
$2V_Z$ 5 measurements, mean 72°, variation 71—74°

Birefringence 6 measurements mean 0,0186 variation 0,0140—0,0245. These data indicate an intermediate composition between diopside, hedenbergite and jadeite, and are very similar to those obtained from omphacites (e.g. Ötztaler eclogite). An X-ray exposure confirmed these results.

The determination of the garnet met with difficulties, due to the fact that no chemical analyses were available, and that X-ray data (the cell edge was determined as 11,61 Å) and optical data ($1{,}811 < n < 1{,}819$) are still insufficient for a reliable determination.

The structure of the eclogites is characterized by idioblastic garnets (up to 0,5 mm) and pyroxenes (up to 1,5 mm) which form a stable mineral association with rutile. As mentioned above, these three minerals alter respectively into epidote-clinozoisite, amphibole and sphene. In order to determine whether the alteration of pyroxene into amphibole occurred under static or synkinematic conditions, the optical orientation of the amphiboles was studied, with the aid of the Universal stage. Pronounced orientation could be observed, and it was therefore concluded that the alteration of pyroxene into amphibole at least started as a synkinematic process.

Amphibolites

These rocks are extremely rare, they only occur at the western limit of the Central complex near the Seaya beach. The amphibolites are composed of a green hornblende some biotite and contain plagioclase with 45 % anorthite. The green amphiboles often show bluish coloured borders. No indications of a preferred orientation of the amphiboles were observed in the thin sections. Mineralogically and structurally the amphibolites show no relationship with the eclogites, but their mode of occurrence is similar to that of the basic rocks of the Central complex.

Epidote-amphibolites

Most of the basic rocks of the Central complex, are epidote-amphibolites. They are characterized by a mineral assemblage of amphibole, epidote-clinozoisite, albite, sphene chlorite, sometimes with calcite and biotite; rutile and garnet occur as relics. Macroscopically the rocks are schistose, but in thin sections no parallel orientation of the minerals has been observed. Like in the gneisses of the Central complex this phenomenon is attributed to strong recrystallization under static conditions.

In contrast with the eclogites, the garnets in the epidote-amphibolites are not idioblastic. They show tension cracks, filled with biotite and chlorite. The garnets contain numerous rutile inclusions, and show strong alteration into epidote and clinozoisite. In several samples garnet has completely disappeared and has been replaced by more or less spharical aggregates of clinozoisite and epidote. From this it is clear that the garnet is no longer stable in the epidote-amphibolite facies; it must be considered as a relic of an older mineral combination. In order to examine its possible relationship with the eclogite garnet, the cell edge was calculated (11,64 Å) and the refringence determined ($1{,}793 < n < 1{,}800$). The similarity of these results with those obtained from the eclogite garnets (11,60 Å; $1{,}811 < n < 1{,}819$) points to a probable relationship. Further evidence for a relation between the eclogites and epidote-amphibolites was obtained from the rutile crystals. These occur in both rock types and are thought to be typical representatives of a high pressure phase, in the epidote-amphibolites they show strong alteration into ilmenite and sphene.

Together with epidote-clinozoisite, amphibole forms the main constituent of the epidote-amphibolites. Probably these amphiboles, which are mostly of the same type as those observed in the eclogites, are alteration products of pyroxene. This theory could not be proved, because the epidote-amphibolites do not contain any pyroxene relicts. The determination of the amphiboles met with difficulties, due to the fact that optical criteria are insufficient for a reliable determination. However, two main groups can be recognized:

1. A bluish green amphibole with strong pleochroism as follows:

   Z bluish green
   Y green
   X colourless-yellow
   Z/c 16—24°
   $2V_X$ 73—75°
   Birefringence 0,019.

   This type is thought to belong to the common green hornblende group. Optically these hornblendes are the same as those mentioned above in the description of the eclogite and amphibolite.

2. A colourless to weakly coloured amphibole, often fibrous, with the following optical properties:

   Z/c 12—16°
   $2V_X$ 75—85°
   Birefringence 0,019—0,020.

These amphiboles are thought to belong to the actinolite group. The two kinds of amphibole occur simultaneously in the epidote-amphibolites, but no conclusive evidence about their genetic relationship could be found. Apart from these two mentioned amphiboles, there are some rare occurrences of other types, for instance a light violet coloured one, strongly zoned with Z/c varying from core to border from 21 to 27°.

Many of the amphiboles show alteration into biotite, especially in the western part of the Central complex. The biotites often have an oblique orientation in relation to the schistosity. A common alteration product of amphibole is chlorite. This process finally leads to the formation of chlorite-albite rocks. The epidote-amphibolites contain plagioclase with an anorthite percentage of about 10. Two modes of occurrence of this albite have been observed:

1. Intergrowth of albite and epidote-clinozoisite. They seem to form a stable mineral combination, indicating that the metamorphic facies of this rock type actually is the albite-epidote-amphibolite facies.
2. Albite forms porphyroblasts, as was also recorded from the gneisses and schists of the Central complex. The inclusions in these porphyroblasts, nearly always amphibole and epidote-clinozoisite, hardly ever chlorite, give some information as to the time of their formation.

Thus it is concluded that the growth of the porphyroblasts was the last phase in the process of retrograde metamorphism, contemporary with the formation of chlorite.

The albite porphyroblasts often show indications of rotation. From the forgegoing it is clear that this must be due to a post metamorphic deformation.

Chlorite-albite rocks

As was mentioned before, these rocks are thought to represent the last stage in the process of static retrograde recrystallization. In thin sections they show the same chaotic structure as the epidote-amphibolites, often without any parallel orientation of the constituents. Sometimes, however, one can still observe relics of garnet and rutile, witnesses of an earlier higher grade of metamorphism. The chlorite rocks show often mylonitic structures, due to post metamorphic shearing.

Glaucophane bearing rocks

This particular rock type was found near Molinos de Celan, and further inwards to the SW, near Loroxo. Contacts with the country rock have not been observed. In a matrix of garnet and presumably jadeite-rich pyroxene, (low birefringence - strong dispersion) large zoned glaucophane crystals occur, bearing inclusions of both jadeite and garnet. The cores of the glaucophanes are richer in Al, and poorer in Fe than their outer rims, as can be concluded from the following optical data:

	core	rim
Z/c	10°	6°
$2V_x$	45°	42°

No preferred orientation of the glaucophane was observed. The garnets occur in several generations. Secondary garnets bear inclusions of quartz, pseudomorphous after primary garnet, which contains primary garnet as inclusion itself. More complications rise from the fact that garnet inclusions in glaucophane bear pyroxene inclusions themselves.

An explanation for the occurrence of this particular rock type is not easily given, but all indications suggest that the parent rock was of the eclogite type, probably richer in Na than the eclogite mentioned before. The glaucophane must be of retrograde origin, comparable with the amphiboles in the epidote amphibolites, but adapted to a Na-rich environment. The occurrence of chloritoid was reported by Prof. I. Parga-Pondal (personal communication).

HORNFELSES

These rocks were already mentioned in discussing the granites. They are common east of the western granite and alternate with gneissic schists. The rocks are strongly banded, and show parallel layers rich in a dark mineral, occurring in relative large crystals. In the field these were determined to be cordierite, but in thin sections no certainty about their nature could be obtained, due to their strong alteration. The rocks, however, show the finegrained structure and non schistose texture typical of hornfelses. If not of contact metamorphic origin, these rocks are at any rate thought to be products of crystallization under static metamorphic conditions. With the other rocks of the Central complex, the hornfelses have in common their strong folding and the growth of albite porphyroblasts.

THE LAGE FORMATION

The augengneiss of the Cabo San Adrian

The outer western part of the studied section is occupied by a lenticular body, composed of augengneisses alternating with planar gneisses and granitic rocks. Going westward from the Seaya beach, the andalusite bearing two-mica schists contain more and more boudin shaped gneissic inclusions. The greater part of the body consists of augengneisses, a coarse grained rock of granitic composition, with eyeshaped alkali feldspars, surrounded by biotite bands. These intersect at an angle of maximum 35°, the bisectrix of which is roughly parallel to the general trend of the strike observed in other parts of the section.

Most of the feldspars have been deformed, but occasionally idiomorphic crystals occur, generally oblique to the strike. Whether this indicates their postkinematic origin, or whether it is to be interpreted from their originally different position in relation to the stress field is not clear.

In the direction of the strike as well as perpendicular to it, the augengneiss grades rather abruptly into gneissic and granitic rocks. Mineralogically of the same composition (quartz-oligoclase-microcline-biotite) as the augengneisses, they only differ from them in texture and grain size. Numerous tourmaline rich pegmatites dissect the augengneiss. The gneisses, granites and pegmatites all show the influence of strong deformation, as can be seen from the strongly bent, generally not broken biotites in the gneisses and granites, and the broken tourmaline crystals in the pegmatites.

The genesis of the augengneisses is an unvolved problem, whether they are of magmatic or metamorphic origin is not known. The irregular and sharp contacts, however, suggest an intrusive origin.

The rocks of the Monte Neme

These rocks belong to a subdivision of the Lage formation, the so called Meda group. This comprises various different rock types such as: granites, augengneisses, migmatites, pegmatites, schists and mylonites.

The region is badly exposed, the relation between the different rock types has not been settled conclusively. However, the general impression is that of a central granitic core with a rim of augengneisses grading into migmatites. Pegmatites are abundant and locally the rocks are strongly mylonitinized. The relationship with rocks of the Central complex still is obscure, the boundary is mostly concordant, but at Punta de Chan de Razo the granitic rocks cut discordantly through the rocks of the Central Complex.

TECTONICS

Folding

The rocks of the Central complex show the influence of strong compression, resulting in intense folding. Most of the gneisses and schists show shear folding. The quartzites show concentric folding, the same holds for most of the basic intercalations in both schists and gneisses. In rocks with a well developed schistosity it is seen that the folding is actually one of the schistosity. Nearly all minor folds are of the isoclinal type, therefore hardly discernable in the field and difficult to reproduce on a map. These minor folds are superimposed on larger ones, in which the above mentioned succession of rocks: from bottom to top gneisses, basic rocks or gneissic-schists and schists occurs. This phenomenon is best demonstrated at the San Miro beach, where a broad anticline is composed of the three known components, each showing strong isoclinal folding. The fold axes of both minor and larger folds are parallel and plunge 10—15° to the SW.

The possible relation between the folding of the schistosity and the recrystallization could be established. As the observed alteration of pyroxene to amphibole in the eclogites started as a synkinematic process, and the epidote-amphibolites and the gneisses s.s. of the Central Complex show evidence of retrograde recrystallization under static conditions, it is believed that the main deformation took place before, and continued during the early recrystallization.

Faulting

In the south the investigated area is borded by an E-W running fault. In the field several indications for the existence of this fault were found.

1. A fault breccia near Beo.
2. Diverging directions of the schistosity in a narrow zone along the fault trend.
3. Discontinuity of several rock types, in the direction of their strike.
4. The occurrence of material, employed for ceramics, along the road Malpica-Buño, originated from the weathering of the schists.

The horizontal displacement of the fault is estimated at 700 metres. The vertical displacement is difficult to evaluate, but from the map it follows that such a displacement must have taken place, uplifting the southern part.

Possible faults parallel to the general strike are much more difficult to prove. The existence, near Molinos de Celan of such a fault separating two different parts of the Central complex, is probable, but no conclusive field evidence has been found. Special attention was paid to the boundary between the Lage group and Central complex. To the west this transition is obscured by a beach. This could indicate faulting. To the east no fault indications were found. Along the Baldayo beach a deviation from the general NE-SW strike direction is so gradual, that flexuring rather than faulting seems probable.

Shearing

In the foregoing, several indications for a post metamorphic shearing were mentioned. In the field as well as in thin sections numerous indications for such a deformation were found. As was stated before, this shearing must have taken place after the recrystallization was completed.