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PETROLOGY OF AN AEGIRINE-RIEBECKITE GNEISS-BEARING PART OF THE HESPERIAN MASSIF: THE GALIÑEIRO AND SURROUNDING AREAS, VIGO, SPAIN

BY

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ABSTRACT

The investigated area forms part of the crystalline basement of the southwestern half of the Iberian peninsula (Hesperian Massif). In it, Precambrian paragneisses of predominantly greywacke composition surround granite-gneisses with whole-rock Rb-Sr ages of 486–500 m.y. Hercynian granites are intrusive into the older rocks.

It is argued that the paragneisses underwent a Barrovian type regional metamorphism (probably low P-T portion of the almandine-amphibolite facies) in the Precambrian, were locally thermometamorphosed by some types of the Cambro-Ordovician granite complex, while in the hercynian orogeny they were again subjected to regional metamorphism, but now of the Abukuma-type (andalusite-cordierite-muscovite subfacies of cordierite-amphibolite facies). The Precambrian metamorphism is represented by elongated quartz, biotite flakes and relics of garnet, all enclosed within early-hercynian minerals, the thermometamorphism by altered, fine-grained cordierite and by fine-grained rock structures, the hercynian metamorphism by the occurrence of cordierite, andalusite and cummingtonite, in appropriately composed rocks, on a regional scale.

The granite-gneiss complex consists of per-alkaline gneiss (containing quartz, albite, microcline, riebeckite, aegirine, lepidomelane, astrophyllite, zircon, fluorite, xenotime, pyrochlore and some less frequent accessories), biotite gneiss (composed of quartz, microcline, plagioclase, biotite, occasionally muscovite or green amphibole, accessories) and a hybrid series of basic rocks both enclosed within and assimilated by alkaline granite-gneiss.

Evidence is presented in support of the hypothesis that the per-alkaline gneisses were one-feldspar granites before their (hercynian) gneissification, which caused separation of the perthites into very pure albite and microcline, both in the maximum low-temperature state and that riebeckite in its present composition was not an original constituent of the per-alkaline granite either.

Considerations on the stability of riebeckite, aegirine and lepidomelane yield P-T conditions compatible with those deduced from the paragneiss mineral assemblage. Sodium, apparently mobile after the separation of the perthites into their composing minerals, migrated into neighbouring rocks, causing the formation of albite porphyroblasts. The influence of pre-hercynian alkali metasomatism from per-alkaline granite is also locally visible.

The hercynian megacrystal, muscovite, two-mica and coarse-grained biotite granites and cordierite-quartzdiorite are petrographically described and their origin and mode of emplacement discussed.

Chemical analyses were made of paragneiss, metasomatosed paragneiss, per-alkaline gneiss, amphibolites, rocks of the hybrid series and of microcline, riebeckite, aegirine and lepidomelane. Optical data of albite, microcline, riebeckite, aegirine, lepidomelane and cummingtonite and X-ray data of albite, microcline, riebeckite and aegirine are given. Of microcline and riebeckite the cell parameters were calculated.

CONTENTS

PREFACE

Since 1956, students of the Department of Petrology and Mineralogy of the Geological Institute, Leiden University, are carrying out fieldwork in Galicia, NW Spain, as part of their undergraduate training program. The results of fieldwork and investigation of the collected hand specimens in the laboratory are laid down in generally unpublished theses. The investigation is often continued after taking the degree and may then lead to a doctoral dissertation. The present paper is the first of a series of dissertations on different areas in western Galicia.

I started mapping the southern half of the present area in the summer of 1956 under the supervision of Prof. Dr. W. P. de Roever. It was continued in 1958. His successor, Prof. Dr. E. den Tex, guided the fieldwork for the dissertation, which was done in the summer months of 1960, 1961 and 1962. Only short visits in order to check some observations made in earlier years were paid to the area in subsequent summers.

Aim of the study has been to describe the rocks found, to clarify their mutual relations and to unravel their genesis.

Acknowledgements

Prof. Dr. W. P. de Roever guided my first investigations in the Galiñeiro area. His interest in the per-alkaline rocks did not diminish after his departure to Amsterdam, from where he gave me valuable advice, which I greatly appreciate.

To the N.V. Billiton Maatschappij I am very indebted for the readily given permission to have some trace elements analyzed in the Analytical Laboratory of the N.V. Hollandse Metallurgische Industrie Billiton, Arnhem and to Dr. A. H. van der Veen for the separation of astrophyllite in the Mineralogical-Petrographical Department, Research Laboratories, N.V. Hollandse Metallurgische Industrie Billiton, Arnhem.

Dr. H. N. A. Priem of the Laboratory for Isotope Geology put pure samples of several minerals from riebeckite gneiss at my disposal. Messrs. R. H. Verschure and L. IJlst kindly performed the laborious separations. Our discussions on the geochronology of the Hesperian Massif were very instructive.

The assistance given by Dr. L. van der Plas and collaborators, who separated two light fractions from riebeckite gneiss with their highly effective equipment and investigated a number of feldspars, is gratefully acknowledged here.

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El Consejo Superior de Investigaciones Científicas y la Comisión Nacional de Geologia han patrocinado y autorizado el presente estudio. Manifiesto mi gratitud a estas instituciones por la posibilidad que me han brindado de trabajar en España.

Deseo expresar aquí mi agradecimiento al Sr. D. Isidro Parga-Pondal, del Laboratorio Geológico de Lage, por el gran interés con que ha seguido el desarrollo de la investigación del Galiñeiro. Las discusiones que he sostenido con él han ahondado muchísimo en mi juicio sobre la geologia gallega.

El progreso de mi trabajo en el campo ha sido facilitado por muchas autoridades y varias empresas de Vigo, entre las cuales figuran: el Excmo. Sr. Gobernador Militar, el Excmo. Ayuntamiento de Vigo, especialmente el departamento de Obras Públicas, el Sr. Consul de los Paises Bajos D. Ceferino Molina Vazquez, el Sr. Comandante de "E.T.E.A.", el Servicio de Obras del Puerto, el departamento de Vias y Obras de la R.E.N.F.E., astillero de Hijos de J. Barreras S.A., empresa constructora Rubarqui S.A. y Ramilo Ltda. A todos ellos deseo expresar mi profundo reconocimiento por la ayuda prestada.

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En Zamanes he sido recibido de manera muy acogedora por D. Domingos Prado y su familia, y en Porriño por D. Manuel Moreira y su familia; la confianza ofrecida por ellos y por todos los vecinos de Zamanes y aldeas próximas al "Holandés", ha sido muy grata y me ha causado gran satisfacción.

I have greatly benefited from the stimulating supervision by Prof. Dr. E. den Tex both of the elaboration of the field data and of the preparation of this paper.

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I. INTRODUCTION

The region to be described in this paper forms part of the province of Pontevedra, one of the four provinces (La Coruña, Pontevedra, Orense, Lugo), that originally constituted the Kingdom of Galicia, in northwestern Spain. It is situated south of the Ria de Vigo, extending from E to S of the city of Vigo (fig. 1). The area comprises the greater part of the municipality of Vigo and smaller parts of those of Gondomar, Túy, Salceda de Caselas, Porriño, Mos and Redondela.

The typically Galician way of disperse settlement makes the indication of limits of built-up areas of towns, villages and hamlets extremely difficult. It has not been attempted to do so on the map (plate 1). The traditional division of the countryside and also of towns and villages is that into parishes, each one celebrating the name-day of its patron saint with a more or less magnificent "fiesta" announced days before by noisy pyrotechnical displays at noon.

Good roads radiate from Vigo. Mainly untarred, metalled roads interconnect them, thus making every low-lying part of the area easily accessible. Of late an increasing number of forest roads is being constructed into the reafforested hills. Due to the dynamical evolution of the area between Vigo and Porriño into an industrialized zone and to the opening-up of the countryside, the pattern of roads will certainly continue to undergo important modifications in the near future.

Agriculture, principally of maize, is wide-spread in the generally fertile valleys. In SW Galicia, the vine is cultivated in a typical way: Parallel rows of granite poles flank paths between the maize fields. They support iron wires, rattan, branches of trees, etc., extended over the paths. The whole is completely overgrown by vines, the grapes ripening overhead.
The hills are covered with a dense vegetation of heather and gorse. About two decades ago, extensive reafforestation with pine and eucalyptus has started.

Climatologically, the area forms the transition from the humid northern Galicia to the "weakly summerdry" (*schwach sommertrocken*) southwestern Galicia (Lautensach, 1964). This transition is conditioned by the general presence of the Azores anticyclone to the west or southwest. The most common weather situation during the summer shows the Azores high over the Atlantic Ocean and a low over central Spain, caused by thermal convection. In between, northerly winds prevail over northwestern Spain, carrying mist and low clouds in the north, but cloudless generally from the Sierra de Barbanza, SW of Noya, southwards.
Because of the neighbourhood of the Atlantic Ocean, the annual rainfall is high, most rain, however, falling in the winter; in summer, periods of stable fair weather are frequently interrupted during one or two days by atlantic fronts, penetrating over the northern part of the peninsula. The daily and annual variations in temperature are small, when compared with other regions in Spain. During periods of fine weather, on-shore winds develop during the day, off-shore winds at night. They can penetrate as far as 50 km inland.
The average air temperature off Vigo in August is .6° higher than that of the seawater under it, giving rise to the formation of mist, which is easily driven inland by the frequent westerly winds (Lautensach, 1964).

The investigated area is to be found on the 1: 50.000 topographical maps published by the "Instituto Geográfico y Catastral, Madrid", sheets 223 (Vigo) and 261 (Túy). Dr. I. Parga-Pondal divided these maps into 20 "quadrants": 5 rows horizontally (A, B, C, D, E), 4 vertically (1, 2, 3, 4). The area under discussion is not limited by the boundaries of such quadrants, a procedure now generally adopted in the systematical mapping carried out by students of the Department of Petrology of the Geological Institute in Leiden. The geological map (plate 1) has been divided into such quadrants, their codification is indicated in the margins. From the official topographical maps only the paths that the author used for his field-work were copied on the map accompanying this paper (plate 1).

GEOLOGICAL SETTING

Northwest Galicia is situated at the apical angle of the roughly triangular Hesperian Massif, which has its base from the southwestern extremity of the province of Algarve, Portugal, to the eastern zone of the Sierra Morena, Spain (fig. 1) and emerged as a stable block after the hercynian orogeny.
The massif is constituted by ante-mesozoic formations, strongly folded, partly metamorphosed during the hercynian orogeny and intruded by predominantly granitic rocks of hercynian and pre-hercynian age. In the main, tectonic structures are disposed in an arc, concave towards the northeast (Thadeu, 1958).

The Galician part of the Hesperian Massif may be divided into the following units, separated from each other by a fault zone:

1. An eastern part, mainly constituted of folded and weakly metamorphosed palaeozoic rocks, called "Grupo oriental" by Parga-Pondal (1963), subdivided and described by, a.o., Capdevila (1966).
2. A western part, mainly composed of basement rocks (in Parga-Pondal's (1963) nomenclature: "Grupo occidental de Lage, Grupo de rocas básicas del lopolito, Grupo gneisico del Complejo Antiguo, Rocas graníticas").

A simplified geological map of the greater part of "crystalline Galicia" is given as fig. 1.

Large parts of western Galicia are underlain by hercynian muscovite- and biotite-bearing granitic rocks, showing either intrusive or anatectic relations with their wall rocks. Metatexitic and diatexitic gneisses, inhomogeneous diatexites and anatexitic granites (Mehnert, 1963 a, b) are common in some areas, a.o. between Cabo Finisterre and Lage and completely absent in others. It is often very hard to determine whether the granitic component in mixed rocks is due to intrusive or anatexitic processes. Confined bodies of two-mica granite are certainly intrusive; there should be a gradual transition from the anatexites mentioned above to these homogeneous granites.

Discontinuous elongate bodies of megacrystal granite, carrying potassium feldspar phenocrysts up to 10 cm, extend along the W margin of the complex of pre-hercynian metasediments and granites between Malpica and Túy. They are intrusive into anatexitic rocks but were in turn intruded by dykes of two-mica granite; their age is therefore intermediate between these two. Muscovite granites and small masses of granodiorite to quartzdiorite are genetically related with the megacrystal granite. The latter rock is also present along the faulted boundary of the weakly metamorphic eastern part of Galicia and the western part, here under discussion. W of Santiago de Compostela another megacrystal granite is exposed. The la Coruña megacrystal granite is very similar to the others. Its relative age, however, could not be established since it has no contacts with two-mica granite.

Megacryst-bearing two-mica granites are younger than the finer-grained types of two-mica granite as is demonstrated by their clearly discordant outlines.

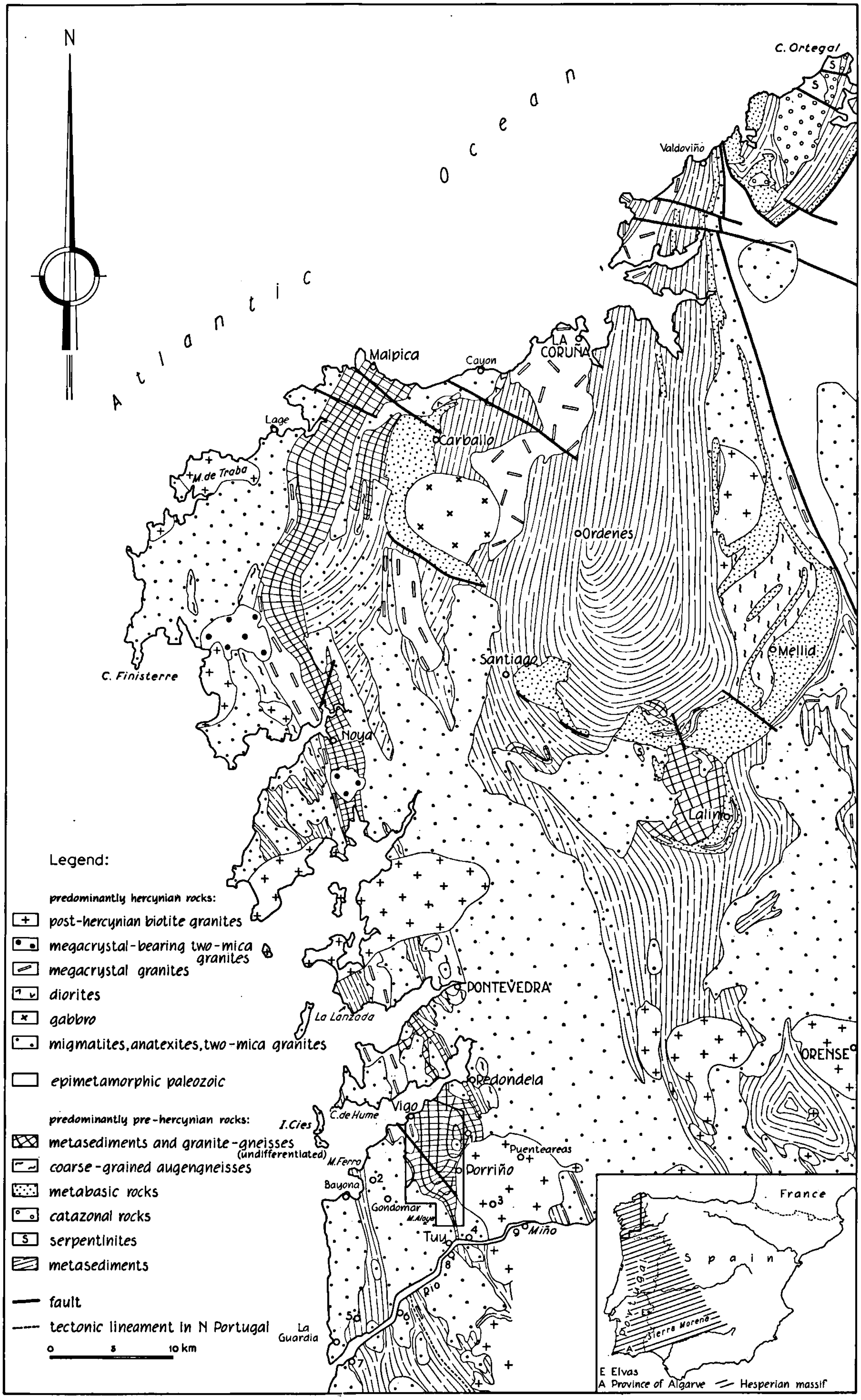


Fig. 1

Simplified geological map of western Galicia, after Parga-Pondal (1963), Carta Geol. de Portugal (1956, 1961) and mainly unpublished data of the Department of Petrology and Mineralogy, Leiden University. Localities mentioned in text: 1: Mos, 2: Nigrán, 3: Salceda, 4: Paramós, 5: El Rosal, 6: Vila Nova de Cerveira, 7: Caminha, 8: Valença, 9: Moncão.

Coarse-grained to porphyritic biotite granites are the youngest granites present, since they are not intruded by others. The complexes themselves are not always homogeneous but turn out to be composed of several types, intrusive into each other. Their hercynian age has been demonstrated by isotopic agedeterminations of two Spanish and three Portuguese granites of this type (see table 19).

All granitic rocks mentioned are mostly emplaced in micaschists, if not in older granitic rocks. The schists, often rich in andalusite (La Lanzada, Cabo de Hume, El Rosal) or garnet and staurolite (e.g.: SW of Lalín), locally contain intercalations of quartzite, graphite schist, amphibolite, calc-silicate rock (La Lanzada) or paragneiss. A conglomeratic lens, very similar to the intraformational conglomerates in the metasedimentary rocks of N Portugal (Teixeira, 1954b) was found near El Rosal (Dr. I. Parga-Pondal, oral communication).

The cartographical distinction between anatexitic metasediments, inhomogeneous anatexitic granites and intrusive but sometimes oriented two-mica granites is very difficult, especially on a simplified map. Parga-Pondal's "Grupo de Lage" contains both non-anatexitic metasediments, and anatexitic metasediments, augengneisses and granites. The present author prefers to consider the process of granitization leading from metatexis to the formation of intrusive two-mica granites as a continuous one, which therefore should be represented on a schematical map with one symbol. The augengneisses, on the other hand, have textures and compositions different from those of metasediments and should in the author's opinion be indicated separately.

A completely distinct group of rocks is the discontinuous annular belt of amphibolites with some serpentinites, peridotites and a body of gabbro, extending from Cayon over Santiago de Compostela and Mellid to Valdoviño. A smaller annular structure through Lalín forms an appendix of the large arc. The complex was denominated "lopolith" by Parga-Pondal, but since it seems to contain rocks of widely differing ages, not all of undoubted intrusive origin, the neutral denomination "Basic Complex" seems to be more appropriate until more is known about it.

The ultrabasic, basic and catazonal rocks of Cabo Ortegal (den Tex & Vogel, 1962) have many aspects in common with the Basic Complex.

Coarse-grained augengneisses are wide-spread especially within the eastern part of the Basic Complex. Similar gneisses are exposed at many places near the N-S trending belt of pre-hercynian metasediments and granites. Parts of the augengneisses were anatectically mobilized.

Complexes of pre-hercynian metasediments and granite-gneisses were found as a discontinuous belt between Malpica and Túy, W and N of Lalín, S of Santiago de Compostela and in a narrow belt, not drawn on the map (fig. 1), from Santiago to the north, continuing along the southwestern border of the Basic Complex. These rocks constitute the "Grupo gneisico del Complejo Antiguo" of Parga-Pondal. The northern half of the zone between Malpica and Túy is clearly delimited by faults at both sides, but this feature is inconspicuous in the southern half.

The presence of strongly foliated granite-gneisses (henceforth also called: orthogneisses) characterizes the complex almost everywhere. Anatectic phenomena are rigorously absent, though the complex has been intruded by two-mica granites.

The metasedimentary country rocks of the orthogneisses are plagioclase-rich paragneisses. Micaschists are rare, amphibolites common, both in paragneiss and in many types of orthogneiss.

The texture of the orthogneisses is variable: some are planar and fine-grained, others are planar but contain potassium feldspar augen, while planolinear augengneisses are also common. Their composition ranges from granodioritic to per-alkaline granitic.

A special type of orthogneiss in the northern part of the zone Malpica-Túy, found to about 50 km S of Malpica, encloses fragments of catazonal and other basic rocks.

The schistosities and foliations are indicated by their symbols on the map (fig. 1). Those within rocks of the Basic Complex are generally parallel to their outlines.

Especially in the NW part of Galicia, the rocks underwent strong phyllonitization along vertical planes, subsequent to the emplacement of most two-mica granites and with a strike subparallel to that of older deformations.

A more detailed summary of the petrology and structural geology of a great part of crystalline Galicia will be given in: Primera reunión sobre geologia de Galicia y norte de Portugal (1966).

The area to be described in the present paper is situated at the southern extremity of the meridionally trending belt of pre-hercynian metasediments and granites (fig. 1), which is not known to continue into Portugal.

Per-alkaline aegirine-riebeckite gneisses occupy a larger area and produce better specimens around Vigo than elsewhere in Galicia: 30 km NNW of Noya (Rubbens, 1963) and N of Lalín (one specimen collected by Dr. I. Parga-Pondal, the outcrop of which was not found again; D. Hilgen, oral communication). The region studied by Rubbens is situated in the part where late-hercynian phyllonitization destroyed much of the original metamorphic textures of the rocks and reduced the size of the constituent minerals. The area around Vigo is therefore very suited for the study of the earlier processes of hercynian metamorphism and deformation.

In Portugal per-alkaline gneisses are known to occur in the province of Alto Alentejo, north and east of Elvas. Contrary to the Spanish gneisses, they were the subject of many publications (a.o. de Sousa Brandão, 1902; Osann, 1907; Lacroix, 1916; Pereira de Souza, 1927; Burri, 1928; Teixeira & Torre de Assunção, 1957, 1958; Aires-Barros, 1958). The Portuguese gneisses are not so rich in free quartz as the Galician ones: they have generally syenitic, in one instance even nepheline-syenitic, compositions.

THE ROCKS OF THE INVESTIGATED AREA

All major types of rock, present in the studied area, will be introduced below. They are represented on the geological map, plate 1.

Recent deposits

Recent sediments fill the floor of the valley of the river Louro, south of Porriño. Since the survey of the author was essentially devoted to petrological problems, the exact distribution of these deposits were not mapped. They are made up of sand, clay (partly workable kaolin deposits) and river terraces, containing flat quartz and quartzite pebbles up to 20 cm across. The terraces have heights of: 5 m, 12–20 m, 30–40 m and 45–70 m above the actual sea-level and are considered to be old terraces of the river Miño, which forms the frontier between Galicia and Portugal. These heights correspond with those of ancient beaches along the coast of N Portugal and S Galicia, thus evidencing that they were caused by deposition (and erosion in the case of ancient abrasion platforms) at times, when the sea-level was considerably higher, viz. during interglacial stages (Parga-Pondal, in: Mapa geol. de España, 1953a; Teixeira, 1952).
The *sands* of a small beach along part of the northern shore of La Guia, locally rich in concentrations of cassiterite and zircon, were incorporated in a morphological

granulometrical and mineralogical study of beach sands of the Ria de Vigo by Sáinz-Amor (1960, 1962) and Sáinz-Amor & Amorós (1962).
The recent deposits will not be treated in this study.

Granitic rocks

It is not difficult to distinguish five types of granitic rocks:

Coarse-grained biotite granite
Two-mica granites
Muscovite granite
Megacrystal granite
Cordierite-quartzdiorite and related rocks

Pegmatites, pegmaplites [1]), granite-porphyry, tourmaline-muscovite rocks and tourmaline-quartz veins are genetically related with these rocks. Except megacrystal granite, all types can be seen in Vigo, either as polished ornamental stone, covering fronts of buildings (coarse-grained biotite granite, cordierite-quartzdiorite, muscovite granite) or as building-stone (two-mica granites, muscovite granite).

The *coarse-grained biotite granite* ("Porriño granite") is a small slice of the pluton of Porriño – Monção, present in the mapped region almost exclusively in a very weathered state, yielding *in situ* arkoses. This material is used for road surfacing. More to the east many outcrops and quarries of fresh rock can be visited. The rock has a pink colour due to salmon-pink microline and perhaps part of the plagioclase. White plagioclase and greyish translucent quartz do not greatly influence this impression. In other parts of the same pluton the colour of the feldspar varies between brick-red and pale rose; consequently the granites assume reddish and pinkish grey tinges respectively.

The *two-mica granites* together occupy a large area of the map, especially along its western and southern margins. They are easy to distinguish from other granites by the presence of both muscovite and biotite. Only the granites related with the cordierite-quartzdiorite display the same characteristic; distinguishing features between the two will be given when mentioning the cordierite-quartzdiorites and associated rocks.
The granite looks weathered with a light yellowish grey colour probably partly due to the presence of limonitic material and partly to the sericitization of plagioclase. Even in quarries of considerable dimensions no differently coloured rock was found. Owing mainly to the alteration of plagioclase, the granites decompose easily and it is difficult to collect compact samples outside quarries. Fortunately, these are present almost everywhere in low-lying parts of the granite bodies in the SW and extreme NW of the area, where the granite is quarried for building stone. The granite between Puxeiros and Porriño is very weathered and has only relatively fresh outcrops where it was trenched for a new section of national road 620.

South of the city of Vigo, some hills are composed of *muscovite granite*. Large quarries in the northern part of the body yield the blocks that are used in building construction and for cutting ornamental stone. When weathered, it is difficult to see the differences between two-mica granites and muscovite granite.

The *megacrystal granite* is rather difficult to map. It decomposes easily, so natural outcrops are rare. About the only ones observed are situated on the slopes of Castro, the hill in the centre of Vigo, but even there the rocks are extremely weathered. To collect fresh samples one has to look for some giant boulders, up to 4 m across,

[1]) i.e.: pegmatites with coarse parts but also sugary-white aplitic portions.

which rest upon the soil on the pine-covered hillsides north of Valladares or one must visit roadcuts and quarries for housing projects. Even in these artificial exposures the granite is more often weathered than not. The rock carries idiomorphic K-feldspar megacrysts, up to 8 cm long, in a medium- to coarse-grained, biotite-rich, granitic to granodioritic groundmass.

Cordierite-quartzdiorite and related granodiorite and granite without any sign of tectonization were found in many localities in a N-S trending zone from the northern margin of the map to the road Zamanes-Porriño in the south. The quartzdiorite is limited in its occurence to the norteastern part of the belt, north of the highway Vigo-Porriño. Granodiorite and granite abound in the south and also along the western margin of the quartzdiorite-zone in the north.

Fresh cordierite-quartzdiorite, in which blue cordierite is often visible with the unaided eye, is present only in boulders with spheroidal exfoliation and diameters mostly varying between one and four metres. They are much sought after for the preparation of ornamental stones but it appears to be very difficult to shape them into the required rectangular blocks since the rock fractures along almost unpredictable planes. In the walls of hollow paths it could be seen that some boulders are not lying *in situ.*

The granodiorite and granite are devoid of cordierite. No spheroidal exfoliation was observed; the rock decomposes easily and is to be found nearly exlusively in the walls of paths and roads. The colour is yellowish grey, darker than that of the two-mica granites because of its higher biotite content. In the granites of this group the plagioclase has a hypidiomorphic appearance, comparable to that of the quartzdiorites. These two features and the composition of plagioclase as measured in thin sections distinguish these granites from the two-mica granites mentioned above. Outcrops of cordierite-quartzdiorite and related granodiorite and granite are generally too small to be represented individually on a 1: 25.000 map. Their area of distribution is therefore indicated with a schematical pattern of symbols.

Only large pegmatites, with thicknesses of at least one metre and often of considerable lengths, were drawn on the map.

Pre-hercynian granite-gneisses

All pre-hercynian orthogneisses have a grey ground-colour in common. Their great variation in habit and composition made subdivision desirable. This is effectuated on the map by overprinting compositional symbols, parallel to the average direction of strike of the rocks. Three main types are distinguished: riebeckite gneiss (*sensu lato*), amphibole-biotite rocks and associated gneisses and the norteastern orthogneiss complex. The latter complex often contains countless inclusions of amphibolite, a rock conspicuously absent in the two former types.

Riebeckite gneisses and several kinds of related rocks are found in a narrow band trending roughly N-S from the peninsula of La Guia to the south. The band is three times displaced N of Zamanes by supposed faults. From Monte Galiñeiro it bends towards the east and seems to be divided into two separate seams. One forms hill 658 m, and ends not far east of it, the other continues across the valley of Saramagal veering more and more to the north until, at the height of the chapel of Virgen de las Nieves, N-S strikes are found again. However, the dips are opposite: easterly in the western band, but westerly here. About 1 km NE of Herbille this band ends after making a rapid turn to the east and again to the north. The thicknesses of the bands are variable, the thickest portions occurring at Monte Galiñeiro ($\pm$ 150 m) and La Guia ($\pm$ 100 m). A narrow band of riebeckite gneiss was found along the eastern slopes of the hills Cepudo and San Bartolomé, southwest of Valladares. All gneisses of this type are well-foliated and fine-grained. Albites reflecting light from their cleavage planes and tiny crystals of dark constituents (e.g. riebeckite, aegirine, lepidomelane, astrophyllite, magnetite) are the only macroscopically recognizable minerals.

In the field, the complex of *amphibole-biotite rocks and associated gneisses* was thought to be about twice as large as the part indicated on the map in grey. Gneisses between this part and riebeckite gneiss to the west have macroscopically an almost similar appearance. Only the investigation of a great number of thin sections revealed their clearly different, viz. metasedimentary, origin. To avoid difficulties in nomenclature during the fieldwork, the whole group has been dubbed "Zamanite complex" [1]). This name will only be used in chapter IV; in other chapters the reader will find the more correct but somewhat unwieldy denomination "amphibole-biotite rocks and associated gneisses".

Paragneiss separates rocks of the group under discussion from riebeckite gneiss in the east and extreme south of the complex; elsewhere the latter two are in contact with each other. North of the NW-SE fault rocks of the Zamanite complex were not found. Some specimens from the northeastern orthogneiss complex have similar mineralogical compositions, but are texturally distinct.

Most rocks of the complex are meso- to melanocratic, medium- to fine-grained and weakly foliated or massive. Amphibole, biotite and – when present – albite can be recognized with the unaided eye. The western part consists uniformly of mesocratic rock, whereas the narrower eastern part displays a great variation of types. Here, compact boulders of rather coarse-grained dark-coloured hornblende-rich rock were found locally. NW and also SW of Herbille it can be observed in paths that meso- and melanocratic rock fragments are surrounded by lighter-coloured rock. Unfortunately the exposures are weathered. Most specimens collected for investigation were lying as float in the neighbourhood.

The name *norteastern orthogneiss complex*, though not very exact because it is meant to include occurrences in the NW and SE quarters of the map area as well, has been chosen because it points to the fact that the rocks are commonest in the NE part

[1]) After Zamanes, a hamlet situated in the northern part of the complex, where the author stayed duing his fieldwork.

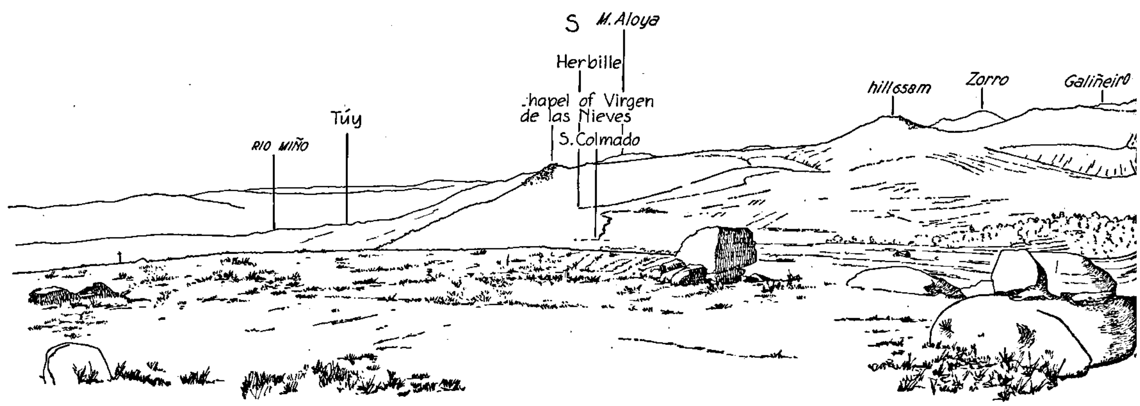


Fig. 2 Panoramic view of the Galiñeiro Range from Las Pereiras.

of the region, at the same time avoiding a specification of their mineralogical compositions. The latter would be difficult because the complex contains biotite, muscovite-biotite and amphibole-biotite gneisses with, for instance, varying accessories, compositions of the constituting plagioclases, and quantities of K-feldspar augen. The rocks have granitic or (less frequently) granodioritic compositions and planar, planolinear and occassionally linear textures.
On the geological map (plate 1) the following occurrences can be distinguished:

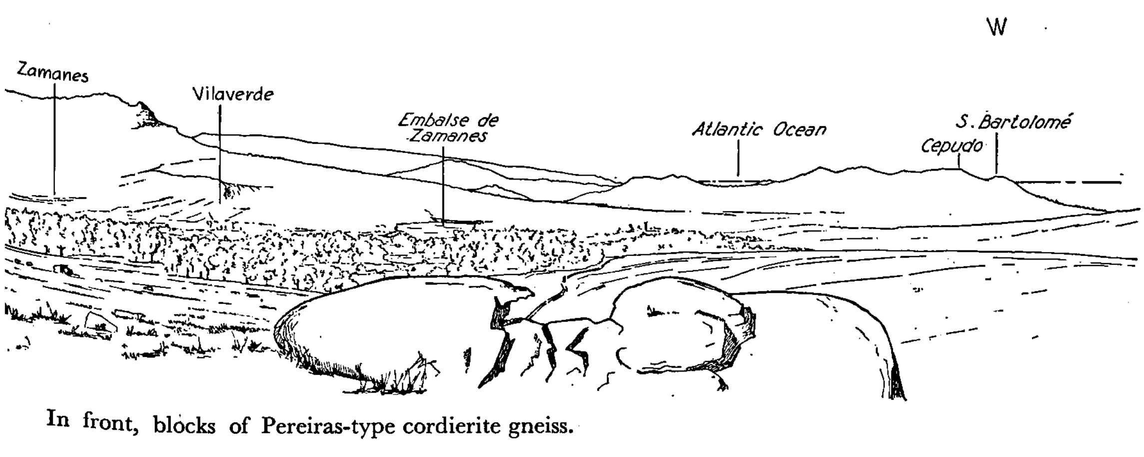
1. A large N-S trending body with a western half dipping to the east, a narrow N-S zone with subvertical dips and an eastern half in which dip and strike are more variable;
2. An oval, dome-shaped, body: "Lonsa dome", situated E of the afore-mentioned occurrence, at its N extremity plunging underneath the latter;
3. Some small orthogneiss lenses between Abelenda and Puxeiros;
4. A leucocratic, less clearly foliated orthogneiss, E of Mosende: "Mosende gneiss";
5. A band of orthogneiss between Babio and Vigo, for the greater part represented by septa or roof-pendants in megacrystal granite.

Amphibolites

Very fine-grained greenish black to greenish grey amphibolites were seen in many parts of the studied region. In natural outcrops the relations with the surrounding rocks are mostly obscure, but in roadcuts, quarries and walls of paths in weathered rock it is clear that the amphibolites occur as lenses in the surrounding rocks. In larger exposures alignment of lenses is not infrequent, thus giving evidence of a probable origin by boudinage. Mostly, however, amphibolites are found as loose fragments, smaller than a few decimetres. The frequency of these fragments and of the rarer outcrops is such, that accurately mapping them on a scale of 1: 25.000 was impossible. They were approximately drawn where they were actually seen or where debris indicates that they should be present near-by. This explains their concentration along roads and paths. The shape of the amphibolite symbols on the map is purely schematical.

Paragneisses

Paragneisses (and a few amphibolites, that will be demonstrated to be of sedimentary origin) constitute the country rocks into which all rocks mentioned so



In front, blocks of Pereiras-type cordierite gneiss.

far were emplaced. They occupy a larger area of the investigated region than any other rock, are richer in biotite and consequently darker-coloured than granite or orthogneiss.
Generally, biotite, muscovite, quarz and plagioclase are the main constituents, but in some cases muscovite or plagioclase are absent. Tourmaline, garnet and cordierite were often noted, while andalusite, sillimanite and microcline are of less frequent occurrence. It is not always possible to recognize these minerals with the unaided eye.
In addition to large areas with predominantly paragneiss, it also occurs enclosed by megacrystal granite and in narrow bands between two-mica granites near the western margin of the map, between two-mica granite and riebeckite gneiss on the western slope of the Sierra de Galiñeiro, completely enclosed by riebeckite gneiss S of Monte Galiñeiro, between the eastern riebeckite gneiss band and biotite-amphibole rocks, enclosed by the norteastern orthogneiss complex mainly in a N-S trending zone and finally west of the "Lonsa dome". Undoubtedly, other inclusions of paragneiss in orthogneiss remained unnoticed because of their cover of vegetation.

Degree of exposure

The degree and manner of exposure of the studied rocks do not facilitate the task of a surveying geologist. Agriculture, vegetation and urban buildings generally conceal the rocks in lower parts of the area. Where cropping out, they are weathered or even completely decomposed. Locally, blocks of hard, fresh rock lie among the vegetation (fig. 2). One doubts whether such exposures are remnants of rock present everywhere around or are distinctly composed lenses, more resistant to weathering. These blocks often did not retain their original orientations. The peasants built low walls around their fields composed of rocks encountered during the farming of their land. These walls provide a good insight in the rock-types prevailing in their immediate surroundings, though sometimes blocks were hauled from elsewhere if they were not sufficiently present in the field itself. Most of the data for the map were collected along paths, roads and other artificial exposures, often also there in weathered or decomposed rock.
Though the area is limited to the NW by the Ria de Vigo, coastal sections are only visible along the shore of La Guia. Elsewhere, the coast has been artificially modified by harbour construction.
Outcrops are more numerous in higher parts of the region, but the rock is still more often than not weathered. Contacts seem to be preferentially overgrown with vegetation. Recently planted, quickly growing pine will increasingly hamper orientation in the terrein. In older wooded parts orientation is already impossible without the aid of aerial photographs.
In general, fresh contacts were hardly ever observed; often, they could be located only approximately. SW of Puxeiros, the contacts of ortho- and paragneiss were constructed from observations in a few paths; they could not be followed in the field. The same is the case with the thin riebeckite gneiss band in Lavadores.

MORPHOLOGY

Differences in resistance to erosion greatly determined the morphology of the area.
Relatively high hills are present in coarse-grained two-mica granites (San Bartolomé, Cepudo, the continuation of the Sierra de Galiñeiro to the south, with a.o. Monte Aloya; fig. 2). Medium-grained two-mica granite and muscovite granite occur in

small intrusions, which fact lowers their chance to survive erosion. It has been noted in adjacent areas that medium-grained surrounded by coarse-grained two-mica granite forms a depression.
Coarse-grained biotite granite is more easily eroded than coarse-grained two-mica granite, a phenomenon also observed elsewhere in Galicia (Parga-Pondal, 1958b); megacrystal granite shows the poorest conservation of all granites.
Riebeckite gneiss seems to be the most resistant rock. Mount Zorro, 713 m, constitutes the highest summit of the area, while the Galiñeiro ridge (fig. 3), hill 658 m and La Guia are also conspicuous morphological features. The norteastern descent

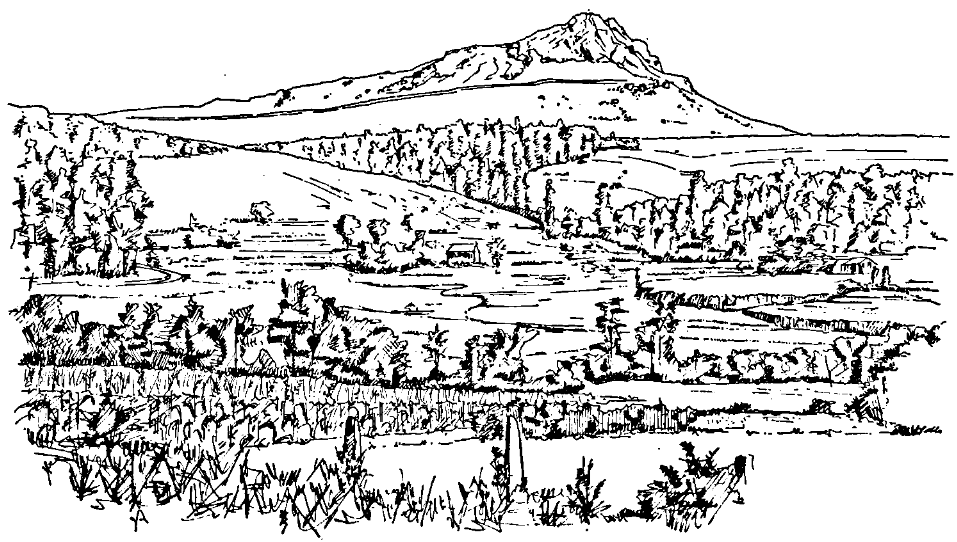


Fig. 3 The northern extremity of the Sierra de Galiñeiro, seen from the road Porriño-Vincios. Riebeckite gneiss is barren, paragneiss covered by vegetation.

of the curved Galiñeiro ridge is a dip-slope. Riebeckite gneiss protected the eastern extremity of the hill, on which the chapel of Virgen de las Nieves is situated, from further erosion (fig. 2).
The N-S elongated ridge between Pedra Cavalaria in the south and the area, several km north of the margin of the map, where another intrusion of coarse-grained two-mica granite forms an even higher relief, is entirely composed of orthogneiss. The Castro of Vigo has probably survived erosion because of the quantity of orthogneiss remnants enclosed within megacrystal granite.

The valley of the river Louro is the southern extremity in Galicia of a very remarkable N-S tectonic zone, which constantly forms a morphological depression, right up to the beach of Baldayo, between Malpica and Cayon (fig. 1). A fault plane or the influence of fault movement were not seen and the fault could therefore not be located within the studied area.
Other faults, causing displacement of geological boundaries and distortion of regional strike and dip, are often visible in the field as straight watercourses or on aerial photographs.

PREVIOUS WORK

The synopsis of earlier literature given below is restricted to publications especially dealing with the Galiñeiro area or presenting important data on rocks also present in that area.

Schulz (1835) was the first to publish a geological map of the then existing Kingdom of Galicia, and to mention some rocks in the author's area: gneiss and schist W of Porriño, granite-gneiss in Vigo and granite N of Túy (the Porriño granite), providing poles for the support of vines.

The morphology and distribution of granite, gneiss, pegmatite, amphibolite and quaternary rocks in the "subregión El Galiñeiro" are described by Valenzuela y Ozores (1856).

Macpherson (1881), the first to mention the gneiss of La Guia (calling it a glaucophane-bearing gneissic syenite) and to provide a microscopical description, did not seize the opportunity to distinguish the amphibole, of which he noted the deep blue pleochroic tinges, as a new species, probably because the mineral was too fine-grained to be separated for chemical analysis. "Orthoclase", quartz and zircon receive attention in the same paper.

In 1883, Macpherson gives a section from La Guia to the Castro of Vigo, along which "glaucophane gneiss', mica-rich gneiss (i.e., paragneiss), granite and, on the top of Castro, a biotite gneiss with oval crystals and aggregates of "orthoclase" and quartz occur.

Additional observations made by him appeared in 1886: a macroscopical and microscopical description of the gneiss of the Castro of Vigo, in which he noted the abundance of Carlsbad twins. He emphasizes the contrast with coarse-grained augengneisses found, a.o., between Redondela and Pontevedra (see fig. 1), in which such twins are rare. The occurrence of a chestnut-brown to opaque pleochroic mica (called lepidomelane in the present paper) in "glaucophane gneiss" S of La Guia is recorded in the same paper.

The gneisses of the Galiñeiro itself were recognized as alkaline gneisses by Quiroga (1892) in a macroscopical and microscopical study of the rock. He pointed out the similarity with the gneiss of La Guia and hinted at the possible existence of a connection between the two occurrences in the field. Though the first description of riebeckite had been published meanwhile (Sauer, 1888), Quiroga called the rocks glaucophane gneisses and the aegirine they contain green amphibole. Parts of the descriptions of Macpherson and Quiroga are quoted in: Mapa geol. de España, 1953a.

After Quiroga, interest in the geology and petrology of Galicia was dormant until, in 1929, Parga-Pondal described nontronite as a new mineral in Spain, found near Saramagal in a rock now for the first time called riebeckite gneiss.

This authority on Galician geology, educated as a chemist, but with a keen interest in geology, devoted a great part of his life to mapping the rocks of his beloved Galicia, and interpreting the data he collected. A great number of publications is on his record; only those of importance to the study of the Galiñeiro area are summarized here.

In a paper on allanite in Galician granites (1933), he mentions the occurrence of large idiomorphic grains of this mineral in the Porriño granite.

A tentative chronological classification of granites in NW Spain followed in 1935.

Results of his extensive mapping on a scale of 1: 50.000, initially carried out completely individually, were published a.o. in 1953 (Mapa geol. de España; an explanation of the 1: 50.000 geological map, sheet 261, Túy), part of which forms the southern half of the area investigated by the present author.

A summary of the geology of the province of La Coruña was published by Parga-Pondal in 1956. Because of the continuation of many structural units in a southerly direction, this article has also been of considerable interest to the present study. Parga's concepts of the major rock units: Complejo Antiguo, Grupo del Lopolito, Grupo de Lage, etc., are set forth for the first time. The Complejo Antiguo is described as a group of intensely metamorphosed and tectonized rocks, with phenomena of polymetamorphism and granitization (leading to the formation of the rocks now distinguished as orthogneisses), that are absent outside the complex. He assigned an age of ± 1200 m.y. to the latter rocks.
Another summary appeared in 1958 (Parga-Pondal, 1958a). The Complejo orthogneisses are considered in this publication as huronian syntectonic granites, the alkaline rocks as later non-orogenic intrusiva. The hercynian orogeny caused folding, deformation (a.o. of two-mica granite), followed by intrusion of megacrystal granite, two-mica granite, coarse-grained biotite granite and the basic rocks of the "lopolith". The faulting of the Hesperian Massif, intrusion of basic dykes, rise of the peneplain with subsequent rejuvenation of the relief are ascribed to the alpine orogeny, together with kaolinization of granites and activity of hot springs, continuing up to the present day.
Parga-Pondal (1958b) payed attention to the distinct morphological habits of the different types of hercynian granites.
The "Mapa petrográfico estructural de Galicia", published in 1963, is a clear demonstration of Parga-Pondal's vast knowledge of Galician geology.
Parga-Pondal & Lopez de Azcona (1965) give results of spectrochemical investigations of specimens of orthogneiss, granodiorite related with megacrystal granite, two-mica granites and post-hercynian biotite granites, the majority collected in the province of La Coruña.

Only a few works of other geologists appeared in the last 30 years. Carlé (1945) presented a concise and valuable structural and petrological analysis of the geology of W Galicia. He considered orthogneiss (called by him biotite-bearing, quartz-rich flasergneiss) as possibly pre- but probably synorogenic hercynian granite.

Torre Enciso (1958) reviews the available data on the formation of rias and actual morphology in Galicia.

Preliminary results of the mapping carried out since 1956 by students of the Department of Petrology and Mineralogy of the University of Leiden under the direction of Prof. Dr. E. den Tex, mainly in the N and NW of Galicia have been presented by den Tex (1961).

The present author gave a description of astrophyllite, found in riebeckite gneiss of the Galiñeiro and La Guia; the mineral was previously not known to occur in Spain (Floor, 1961).

Arribas Moreno (1963) described a radioactive gneiss, found ± 300 m S of San Colmado in a study on the mineralogy and metallogeny of Spanish uranium deposits.

Avé Lallemant (1965) is an abridgment of an unpublished Master's degree thesis for the University of Leiden and deals with the area NW and W of Noya.

Publications on the geology of N Portugal proved of considerable interest to the student of Galician rocks. Apart from the works by petrologists from the Municipal University of Amsterdam (see introduction of ch. II), the following papers deserve special mention: Teixeira (1954a; 1955); Westerveld (1956); Oen Ing Soen (1960); Torre de Assunção (1962); Sluijk (1963); Carta geol. de Portugal (explications of 1: 50.000 sheets I-A: Valença (1956) and I-C: Caminha (1961), both situated immediately south of the river Miño).

THE FRAMEWORK OF THIS STUDY

Field and laboratory observations on the groups of rocks established above are brought together in the descriptive chapters II–VII, structural data, including a description of the geological map (plate 1), in chapter VIII. The last chapter, containing all interpretations and conclusions and only summaries of the observations that led up to them may be read as a direct continuation of this introduction. When necessary, the descriptions of the observations can be looked up in the pertinent petrographical chapters. In this way the author hopes to spare readers not interested in the local circumstances the perusal of the whole work.

Remarks on terms, symbols, methods used and on accessibility of collections

The term *foliation* has been used in the sense of Harker (1956; p. 203), viz.: 'a more or less pronounced aggregation of particular constituent minerals of the metamorphosed rock into lenticles or streaks or inconstant bands, often very rich in some one mineral and contrasting with contiguous lenticles or streaks rich in other minerals'. The author prefers this definition because the foliated orthogneisses are generally not schistose in the sense that they break easily along the planes of foliation. Paragneisses, on the other hand, contain parallel-oriented micas bringing about a more or less pronounced *schistosity*.

x, y, z are crystal axes; α, β, γ and ε, ω are refractive indices or directions of the same of respectively biaxial and uniaxial minerals. Plagioclase has been determined in sections perpendicular to α, γ or x, unless stated otherwise. Optic axial angles were estimated using the graph of Tobi (1956).

Unless stated otherwise, the numbers of specimens and X-ray powder patterns are registration numbers of the collection of the Department of Petrology, Mineralogy and Crystallography, Geological Institute, Leiden. The specimens and thin sections of the author's collection are kept in the same institute. The specimens will be transferred to and kept in the "Rijksmuseum van Geologie en Mineralogie", also in Leiden, after the completion of additional investigations.

Small parts of specimens are generally available for exchange with interested readers.

II. THE GRANITIC ROCKS

Notwithstanding their great areal development, the author did not think it necessary to devote much time to the study of the granitic bodies, as even the larger granites are homogeneous. The description of a few specimens will therefore suffice. Moreover, the coarse-grained biotite granite and the two-mica granites show extensive development in northern Portugal, where they were elaborately investigated by students from the Municipal University of Amsterdam. The descriptions of these granites could often be quoted here without any modification. For additional information the reader is therefore referred to: Schermerhorn (1956), Oen Ing Soen (1958), Brink (1960) and Priem (1962).

PETROGRAPHY

Coarse-grained biotite granite ("Porriño granite")

The outlines of the crystals of the constituent minerals are only seldom regular and the texture of the rock is generally panxenomorphic inequigranular (fig. 4g). Microcline rarely exceeds 3 cm, Carlsbad twins and perthite lamellae are macroscopically visible. In some cases a white rim surrounds a pink feldspar. Plagioclase ranges up to 1 cm and quartz to about 8 mm. Booklets of black biotite (usually not longer than 6 mm) complete the macroscopical picture.

Only along one path a very weathered but sharp contact with paragneiss was observed. Thermometamorphic influence could not be detected, probably at least partly because the surrounding rocks were already regional metamorphic at the time the granite intruded. No xenoliths were found in this granite.

Though texturally different (the rock under discussion has no distinct megacrysts and groundmass), it is mineralogically very similar to the coarsely porphyritic biotite granites so common in northern Portugal. The microscopically visible relations and interreactions of microcline, plagioclase and quarts in both types appear to be the same.

The description following below was made of a thin section from a rock fragment collected on a building site in Porriño (309). One slide of a coarse granite like the one under discussion is not enough to make a quantitative statement. From the study of polished slabs it is evident, however, that microcline is the predominant constituent.

Quartz has weakly undulose extinction. Grain boundaries are regular and the maximum size observed is 8 mm. Myrmekitic quartz is rather common.

Microcline reaches 23 mm in the studied slide. The plane of a Carlsbad twin is irregularly curved. Vein perthite with polysynthetic twinning on (010) is common. In addition, small spindles of perthitic plagioclase are observed between the vein perthites (cf. Priem (1962); plate XI). Cross-hatch twinning is not very well developed. No increase of the intensity of this twinning towards the vein perthites was seen. In the only big crystal present in the thin section small plagioclases are oriented parallel to its boundary. In general, the outlines of the microclines are irregular and often attacked by neighbouring plagioclase under the formation of myrmekite. The mineral is slightly kaolinized.

Plagioclase ranges in size up to 1 cm and is present in two roughly separable generations.

The first (and older) generation is clearly zoned, with cores up to basic oligoclase and rims of albite or acid oligoclase. Both normal and oscillatory zoning occur; inner zone boundaries are idiomorphic. The cores are generally altered into sericite with minor amounts of separate muscovite, prehnite, carbonate and also into saussuritic intergrowths of these minerals with members of the epidote-group. Lamellar albite twins and simple Carlsbad or albite-Carlsbad twins were observed; (001) twinning is rare. These plagioclases are older than microcline, because the latter mineral surrounds small plagioclases (so called "Frasl-inclusions" after Frasl, 1954) belonging to this generation. Where in contact with microcline, crystals of the older generation have albitic and in places myrmekitic rims, the transition to more basic plagioclase being rather abrupt. Even when the included plagioclase has regular outlines, the plagioclase of the rims protrudes irregularly into microcline. It is therefore considered to be replacive towards the latter mineral.

The rims form a second generation together with crystals of weakly altered plagioclase having irregular, discontinuous twin lamellae (only albite law) and no conspicuous zonary structure. One spot in the studied thin section shows very conclusive relationships between microcline and younger plagioclase: In the microcline, perthitic veins are present; between this microcline and the neighbouring ones, the crystal has a rim of plagioclase with the same optical orientation as the vein perthite. An adjacent plagioclase with properties as outlined immediately above has in its turn the same orientation as rim and vein perthite; moreover, it includes some microcline patches of the same orientation as the microcline described above and sends amoeboid protuberances into that crystal. So the whole strongly suggests that late plagioclase grew at the expense of microcline.

Biotite is very dark-coloured with pleochroism from dark brown (nearly opaque) to straw-yellow. The flakes often occur in clusters, are only locally altered into chlorite, opaque minerals and titanite, and surround apatite and zircon crystals.

Apatite in idiomorphic prisms is concentrated in and around biotite.

Zircon is found as (hyp)idiomorphic crystals up to .25 mm, but normally the mineral is smaller than .1 mm.

Apart from the *titanite* that originated from the alteration of biotite, a few crystals (up to .35 mm) with included opaque ore were also recorded.

Fluorite as xenomorphic inclusions in microcline, *allanite* and an *opaque mineral* are the other accessories in the coarse-grained biotite granite.

Two-mica granites

The intrusions belonging to this group are homogeneous on the scale of an outcrop and often also when a large part of the complete body is taken into consideration (as far as the discontinuous exposures do not obscure reality). They are frequently cut by pegmatites; veins of leucocratic granite with little biotite can be observed in many quarries (and in the walls of houses in Vigo).

A weakly oriented fabric is sometimes visible, in inequigranular types more easily than in equigranular varieties, because in the former oriented feldspar laths accentuate the parallel texture shown by some mica flakes. Granite-gneisses with strongly oriented micas as present a.o. between Bayona and La Guardia and on the Cies Isles were not encountered in the mapped area.

Contacts with gneiss are sharp within a few metres (or less) in the few localities, where they could be observed. The granite along the shore of La Guia peninsula shows very sharp contacts with paragneiss rafts and riebeckite gneiss. The rotated paragneiss xenoliths offer extremely convincing evidence for an intrusive emplacement of this granite (fig. 5). Apart from the immediate vicinity of their contacts, xenoliths are conspicuously absent in the two-mica granites. Macroscopically, no thermometamorphic influence was noticed in the surrounding paragneisses. In the riebeckite gneiss that has been intruded by granite along the shore of La Guia peninsula and on the E slope of San Bartolomé, metasomatic influence caused the replacement of riebeckite by iron-rich biotite. Locally, a nebulitic biotite gneiss is present instead of riebeckite gneiss (see next paragraph). These features and the microscopically detected effects of the granites on paragneiss will be described petrographically in chapters III and VII respectively; a genetic discussion will follow in chapter IX. The foliation of the gneisses is generally subparallel with the granite contacts.

A glance at the geological map (plate 1) suffices to show that contacts of two-mica granites among each other are not frequent. Where they should be present the cover of vegetation often obscures them. Mostly, however. narrow septa of gneiss lie between the various bodies. A very interesting rock of this kind is a nebulitic biotite gneiss found in several places between San Bartolomé and the road from Vincios to Nigrán. It is located on the margins of medium-grained, inequigranular two-mica granite to the east and coarse-grained, inequigranular two-mica granite to the west.As argued in chapter IX this septum is probably a "ghost" of riebeckite gneiss.

In the field six types of two-mica granite could be distinguished. Short descriptions follow below together with some remarks on properties that are characteristic of each type.

1. *Coarse-grained inequigranular two-mica granite.* Potassium-feldspar is present in larger crystals (normally up to 2 cm, one crystal of nearly 7 cm) than the other constituents of the rock (smaller than 5 mm). Both irregular and lath-shapes were frequently noted (fig. 4a).
2. *Coarse-grained equigranular two-mica granite.* Large potassium-feldspars are not present, while plagioclase, quartz and micas have coarser grain than that in the preceding type (grains frequently over 5 mm) (fig. 4b). This granite is the only one that is accompanied by large quantities of pegmaplite [1]), leucocratic albite-quartz-muscovite rocks, locally abundant crystallization of tourmaline in neighbouring paragneisses and tourmaline-quartz veins. Within a few metres from the contact with the granite, *lit-par-lit* injection into adjacent paragneiss has been frequently noted.
3. *Medium- to coarse-grained equigranular two-mica granite.* Grainsize varies a little, but is always smaller than that of type 2 (fig. 4c).
4. *Medium-grained inequigranular two-mica granite.* Idiomorphic laths of potassium feldspar (up to 35 mm, mostly smaller than 25 mm) are present in small amounts (only a few per square decimeter). Less individualized potassium feldspar is much more frequent and up to 2–3 times the size of plagioclase and quartz which normally vary between 2 and 4 mm (fig. 4d).
5. *Medium-grained equigranular two-mica granite.* Locally biotite is nearly absent. Maximum grainsize variable between 2 and 4 mm (fig. 4e).
6. *Fine-grained equigranular two-mica granite.* The nomenclature of this granite is not according to the conventional use of the word fine-grained. All grains are smaller than in any of the granites mentioned above, but not under 1 mm as required by convention (fig. 4f). Exposures of this type are of common occurrence in the megacrystal granite, SW of the city of Vigo, but the areal development is unimportant.

In all studied samples potassium feldspar is the predominant feldspar. The microscopical texture is panxenomorphic inequigranular. After the fieldwork was completed, it appeared in the laboratory, that two specimens contain plagioclases with a higher anorthite-content than all the others. They will be described separately after a discussion of the mineralogy of the normal two-mica granites. Since types listed above show strikingly similar mineralogical compositions and textural relations, a summarizing account will suffice.

[1]) see note, p. 14.

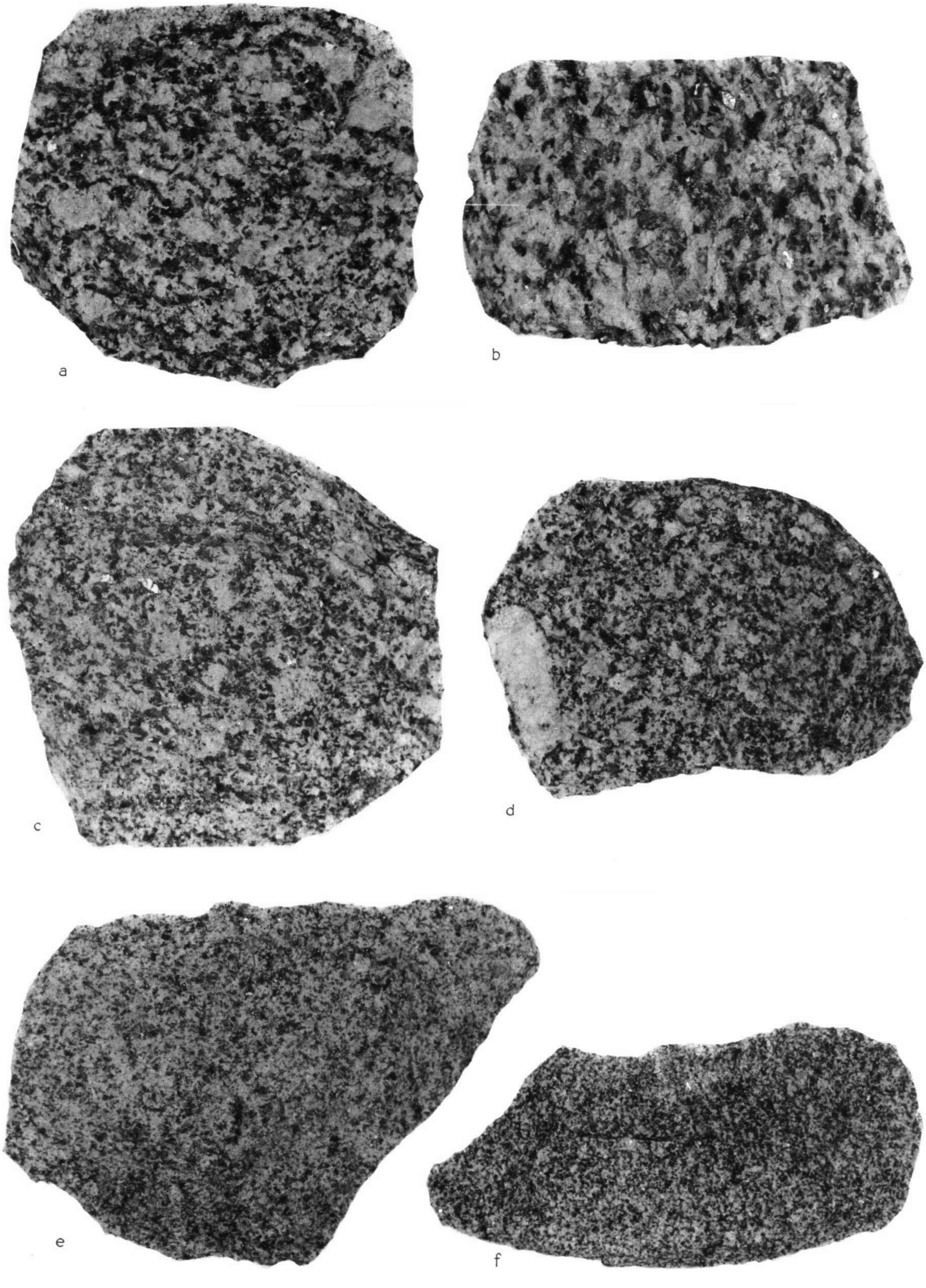


Fig. 4 Two-mica granites. a: coarse-grained inequigranular (629); b: coarse-grained equigranular (504); c: medium- to coarse-grained equigranular (599); d: medium-grained inequigranular (649); e: medium-grained equigranular (445); f: fine-grained (642).

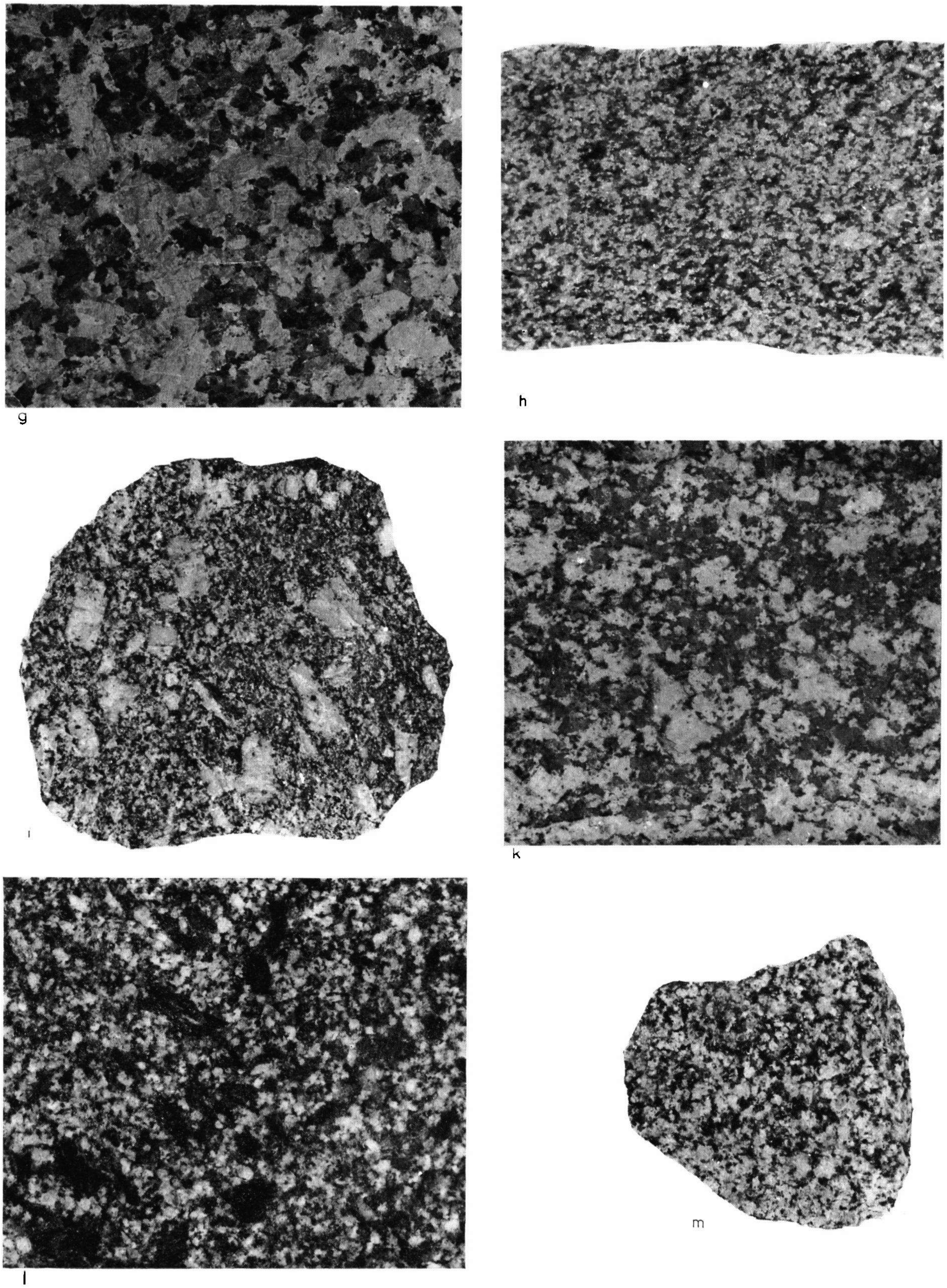


Fig. 4 g: coarse-grained biotite granite (polished surface); h: muscovite granite (polished surface); i: megacrystal granite with idiomorphic microclines (683); k: megacrystal granite with xenomorphic microcline (polished surface); l: cordierite-quartzdiorite with dark-coloured xenolithic aggregates (polished surface); m: granite associated with cordierite-quartzdiorite (669).

Quartz has undulose extinction, irregular grain boundaries and includes countless very thin long needles of a highly refractive, strongly birefringent mineral (rutile?).

Microcline is the only potassium feldspar noted. It is present as large hypidiomorphic crystals with Carlsbad twinning and inclusions of hypidiomorphic plagioclase, quartz (sometimes in micrographic intergrowth) and biotite. Smaller crystals are mostly xenomorphic. Both have cross-hatch twinning and show some development of vein and patch perthite. Only in the rocks of group 3 perthite is present in considerable amounts. Apart from the rather coarse varieties narrow spindle-shaped perthite was also observed. Microcline is attacked by younger plagioclase, sometimes in myrmekitic intergrowth with quartz, but in other instances microcline is replacive towards older plagioclase. Perthite and myrmekite are generally not so well developed as in coarse-grained biotite granite and megacrystal granite.

In *plagioclase* no higher anorthite-content than 11 % has been measured, a fact that distinguishes this group of granites from most other granites found in the map area. Small

Fig. 5 Medium- to coarse-grained equigranular two-mica granite intrusive into paragneiss. Shore of La Guia, Vigo.

hypidiomorphic plagioclases enclosed in big microclines constitute the only exception. Some of them are clearly zoned with oligoclase cores (16 % An) to pure albite rims. Outside microcline, however, zonary structures in plagioclases do not exist (though some show sericitized cores or zones, with other parts of the crystals less altered). The mineral has a hypidiomorphic to xenomorphic habit and is twinned mostly after the albite law (narrow lamellae). Albite-Carlsbad twins, lamellar (001) twins and glide-twinning on (010) were seen in a few crystals. In addition to sericite, muscovite with in some cases crystallographically determined orientations is a common alteration product.

As all plagioclases now have albitic compositions it is not so easy to discriminate between first and second generations as was done in the section on the coarse-grained biotite granite. Some facts can be deduced from the observations: The small plagioclases in microcline, those with sericitized cores or zones, with albite-Carlsbad and (001) twins and plagioclases replaced by microcline with boundaries influenced by structural directions of the plagioclase (e.g. twin planes) probably belong to a generation, older than much or all of the potassium feldspar. On the other hand, albite with discontinuous polysynthetic (010) twinning, with myrmekite or occurring as rims around microcline and sometimes invading that mineral, represents the second generation, younger than potassium feldspar.

Thick booklets of *muscovite*, longer and much thicker than the biotite flakes in the same samples, are characteristic of the granite under discussion. In one sample a booklet five times thicker than long was observed! The edges are normally very irregular, not rarely forming symplectitic or dactilitic intergrowths with quartz. Muscovite surrounds biotite but also occurs included in that mineral. Around zircons light brown pleochroic haloes have developed.

Biotite with pleochroism from red-brown to straw-yellow is less abundant than muscovite. As stated above its flakes are smaller and especially thinner than those of muscovite and they are often intergrown with the latter mineral. Alteration products are: green biotite and chlorite with sagenite needles, anatase (noticed in two sections) and brookite (in one thin section). Zircon and apatite are frequently observed inclusions in biotite.

Xenomorphic grains and slender prisms of *apatite* are very common.

Well-rounded crystals, turbid xenomorphic grains and some small prisms (a.o. in muscovite) of *zircon* occur in all samples.

Opaque minerals are lacking in more than half of the studied samples. Some limonite is mostly present.

The two samples that have different mineralogical characteristics will be described below. To avoid repetition, only differences with the „normal" two-mica granites will be mentioned.

The texture of 676, collected just outside the map area, S of Vincios, is macroscopically identical with that of rocks in group 4. Big muscovites, however, are absent.

Under the microscope the presence of (sometimes oscillatory) zoned *plagioclases* with cores of acid andesine and rims of intermediate to acid oligoclase is very remarkable. Against microcline, a narrow albitic rim has developed. Tiny hypidiomorphic plagioclases are included in a big microcline crystal with their longest sides parallel to the crystal outlines of their host ("Frasl" inclusions). Externally, the plagioclases outside the microcline are xenomorphic. The internal zonary structure, often reflected also by sericitization of certain parts, is much more regular. Myrmekitic intergrowths with quartz invading microcline are common.

One hypidiomorphic *microcline* with a length of 8 mm encloses an idiomorphic biotite flake and some high-quartz pseudomorphs in addition to the already mentioned plagioclases. Other microclines in the thin section are smaller and xenomorphic.

Muscovite surrounds feldspar and quartz poeciloblastically. Symplectitic and dactilitic intergrowths were also observed. The picture suggests an early stage of the formation of the big muscovites of the "normal" granites of this group. Very slender needles of *sillimanite* occur in some places in and around muscovite. *Apatite* has not been encountered in this sample.

642 belongs to the fine-grained equigranular granites (type 6). As it does contain muscovite booklets it is macroscopically undistinguishable from albite-bearing members of the same type.

Plagioclase has the same composition as in 676, myrmekite was measured to occur in a host with 18 % An. The rock being equigranular, only xenomorphic *microcline* was encountered. Like the "normal" granites, this sample contains xenomorphic grains and slender prisms of *apatite*.

Muscovite granite

In the southern extremity of the body the few outcrops present nearly alternately show muscovite granite and fine-grained, equigranular two-mica granite. As the rocks are mainly very decomposed and the vegetation is dense, the accuracy of the mapping should be called poor. Sharp but very weathered contacts with paragneiss were observed along a path and a road in the southeastern and southern part of the body. The muscovite granite also has contacts with megacrystal granite (of which some blocks are enclosed by the former) and should be in contact with orthogneiss too, but that was never actually seen. A block of orthogneiss was found in muscovite granite by stone-masons, but had been removed already when the author visited the quarry. If the masons' account is accurate, the lineation of the xenolith had an E-W direction, i.e. it had been rotated by the granite. Apart from these marginal occurrences the granite is free from xenoliths.

A weak foliation or preferred orientation of micas has been recorded (fig. 4h). The equigranular rock has a grey colour; the maximum grainsizes measured in thin sections vary from 3 to 5.5 mm, the rocks with the finest grain being restricted to the NE part of the body, where most of the quarries are situated. Macroscopically visible are: grey quartz, milky white, rather altered feldspar, muscovite, some biotite and black tourmaline and an occasional garnet.

Under the microscope the rock has a hypidiomorphic texture. The four thin sections studied show such striking similarities that their descriptions were merged into one.

Xenomorphic *quartz* with very irregular grain boundaries and undulose extinction displays strong variation in grain-size in each thin section.

Microcline, generally xenomorphic too, shows abrupt changes in the intensity of the cross-hatch twinning. Often, this is accompanied by different degrees of kaolinization. There is a weak development of fine perthite. Only one Carlsbad twin was found.

The *plagioclases*, hypidiomorphic and some idiomorphic, have a very low anorthite-content (0–5 %). Zonary crystals are lacking; lamellar (010) twins and combination twins on the same composition plane were noticed in all thin sections. 615 contains some (001) twins and slightly bent crystals with glide lamellae as well. The maximum grainsize varies from 2.5 mm in the finest to 5 mm in the coarsest sample. Many albites are strongly corroded by microcline, especially in their interior parts. Arguments in favour of the replacement of albite by microcline are the continuous twin lamellae on either side of microcline patches and the fact that the development of microcline has not rarely been arrested by a twin lamella of its host. Albite replacing microcline was also observed. These crystals with discontinuous polysynthetic twins seem to be the result of the coalescing of many fragments with slightly differing optical orientations. Muscovite is often present as an alteration product in albite, some flakes having crystallographically determined orientations.

Muscovite in thick booklets with maximum lengths from 1.5 to 3.5 mm and light-brown pleochroic haloes around zircons has no irregular terminations as in the two-mica granites. The crystals are nearly unbent. Small muscovite flakes occur as alteration product in albite.

Of *biotite* only two flakes were observed in two samples; in one intergrown with muscovite, in the other embedded in quartz.

In 695, *garnet* is concentrated as often idiomorphic crystals up to 1 mm along a quartz vein. In the other sections no garnet happened to be represented.

The presence of small olive-green *tourmaline* grains (.04 mm) is restricted to the same sample as the garnet. It is visible with the unaided eye in 628, but lacking in the slide of that sample.

The thin section of sample 660 contains many xenomorphic isometric grains (up to 2.5 mm) of *beryl*.

Apatite crystallized in fine grains (.8 mm) in the coarse granite, but in coarse grains (up to 3 mm) in the fine-grained muscovite granite.

Zircon is rather scarce. In two samples the mineral was not found. In the others a few rounded crystals were noted; some muscovites enclose tiny zircon prisms.

Megacrystal granite

Especially the northern part of the megacrystal granite body contains many blocks of orthogneiss (eastern half) and paragneiss (western half). In size they range from a few decimetres to many tens of metres. The number of inclusions is such that the author has not seen one single exposure in the western part of Vigo, where megacrystal granite is the only rock type present. As the greater part of these blocks appears to have retained its regional strike it is perhaps more realistic to think of a granite "stockwork" than of a granite body. Both scale of mapping in respect of size of included gneissblocks and poverty of good exposures make a clear delimitation of granitic and gneissic components impossible. It is not known whether the ratio of granite to gneissic inclusions increased towards the south. The number of good exposures is smaller because the rural houses are rarely founded on solid rock while new secondary roads are made with the removal of as little rock as possible. Mapping is therefore the result of a much smaller amount of observations over a larger area. The fact that the southern part of the megacrystal granite is intruded by various kinds of two-mica granites and by muscovite granite renders an acceptable reproduction of the reality on the map even more difficult.

No thermometamorphic influence of the megacrystal granite on the surrounding and enclosed metamorphic rocks is evident in the field. Possibly the recrystallization of the orthogneisses was stimulated somewhat by the granite intrusion (cf. chapter VI).

When examined with the unaided eye, the fresh megacrystal granite has a clearly porphyritic appearance. Microcline megacrysts up to 8 cm, but normally between 2 and 5 cm, are embedded in a groundmass consisting of quartz, feldspar and biotite with a maximum grainsize of 5–7 mm. In some samples, the microclines are idiomorphic with enclosed biotite flakes parallel to the boundaries of the crystals (fig. 4i). In others, megacrysts are xenomorphic and do not contain regularly oriented biotites (fig. 4k). Both types of megacrysts also occur together in one sample. Carlsbad twins are common. On the eastern slope of the Castro of Vigo the megacrysts are oriented N-S, elsewhere a preferred orientation is seldom apparent. In an outcrop along the Avenida del Castro in Vigo megacrysts were observed to be arranged parallel to the boundaries of enclosed orthogneiss and amphibolite fragments.

The groundmass is rich in evenly dispersed biotite; the aspect of the fresh rock is that of a granite with white megacrysts in a grey groundmass.

The weathered megacrystal granite is at first sight not easy to distinguish from inequigranular two-mica granite, especially where very large megacrysts are lacking in the former. On closer inspection, the absence of muscovite is a good criterion, though sometimes the presence of bleached biotites is rather misleading. The large microclines are less well defined in inequigranular two-mica granite than in the granite under discussion. In some cases, these criteria are not conclusive; it is then necessary to collect a relatively fresh sample and to determine the An-content of the plagioclases in a thin section (see below).

The main cause of the decomposition of this granite seems to be the rapid alteration of plagioclase. Microcline, quartz and biotite are less altered and can easily be picked out of weathered surfaces.

In thin section, many features common in the coarse-grained biotite granite are observed again. One of the most conspicuous differences is the fact that the megacrystal granite is slightly tectonized. Quartz is undulose, its grain boundaries are often irregular, while bent plagioclases with glide-twins were observed in 640. Macroscopically this tectonic influence is not visible. North of the Ria of Vigo, however, megacrystal granites that underwent phyllonitization to a varying degree are common.

The results of the study of five thin sections will be summarized below. The texture of the rock as a whole is hypidiomorphic porphyritic, that of the groundmass hypidiomorphic inequigranular. In the groundmass the amounts of microcline and plagioclase are near to equality. In four sections microcline predominates somewhat, in the fifth (640) plagioclase is a little more abundant. Quartz is present in about the same quantity as either of the feldspars.

Quartz is represented as undulose xenomorphic crystals with irregular outlines, measuring up to 6 mm. Locally quartz clearly fills the spaces between hypidiomorphic plagioclase crystals. Myrmekitic intergrowth with plagioclase is common in all thin sections; micrographic intergrowth with plagioclase has been observed in two, with microcline in one section.

Like the coarse-grained biotite granite, the megacrystal granite contains two clearly distinct generations of *plagioclase*.

The older generation, comprising both separate crystals and smaller ones enclosed within microcline, is present as hypidiomorphic crystals, up to 7 mm long with normal or oscillatory zoning. Against quartz the outlines are often idiomorphic. The core is basic or intermediate oligoclase and the rim intermediate or acid oligoclase; in 640 one core has an An-content of 43 %. Carlsbad, albite-Carlsbad and lamellar albite twinning are common while (001) twins were also noted. Bent crystals with glide lamellae occur in 640. The thin section of 854 contains an example of a combination twin as described by Ross (1957) and encountered in Portuguese coarsely porphyritic biotite granite by Oen Ing Soen (1958) and Priem (1962). In this plagioclase generation alteration is common into sericite, muscovite (with some crystallographically determined preferred orientations), epidote (only in 640) and a (zeolitic?) mineral with much lower refringence than the plagioclase and weak or very weak birefringence. Its properties were difficult to determine, since it disappeared nearly completely during the preparation of the thin sections. This mineral seems to be largely responsible for the decomposition of the plagioclase and therefore of the whole granite, as was argued in the section on the macroscopical properties of the rock.

The second generation plagioclase is younger than microcline, because it invades that mineral in myrmekitic intergrowths with quartz. Albitic rims around first generation plagioclase belong to the second generation, since they show an abrupt transition into the interior oligoclase but pass gradually into myrmekite-bearing plagioclase when microcline is the adjacent mineral. Blastic plagioclase crystals with narrow discontinuous albite lamellae and no conspicuous zonary structure also represent this generation. The same phenomena were observed in the coarse-grained biotite granite.

Microcline is the only modification of potassium feldspar present. It shows perthitization in patches and narrow veins but less intensely than in the coarse-grained biotite granite. Cross-hatching is well developed; in 855 the intensity of this twinning increases towards the perthitic albite. The mineral is twinned after the Carlsbad law and has often inclusions of small plagioclases with acid rims. The biotite inclusions mentioned in the macroscopical description of the granite were rarely seen through the microscope, because no section cutting an idiomorphic megacryst was made. Myrmekitic plagioclase often attacks microcline along its boundaries. Micrographic intergrowth with quartz was found in several microcline crystals in 855. Microcline crystals longer than 11 mm are absent in the studied sections. The mineral is slightly kaolinized.

On the other primary constituents a few remarks will suffice.

Red-brown *biotite* is crowded with apatite and zircon inclusions. It is altered in varying degrees into chlorite with sometimes titanite or sagenite. Slightly bent crystals were noticed in three thin sections. The rather thick booklets reach lengths of 5 mm.

Muscovite has been mentioned already in the paragraph on plagioclase as an alteration product of plagioclase. In addition, a few flakes that do not seem to have originated from alteration, are present in biotite and feldspar.

Prisms and xenomorphic grains of *apatite* are more abundant than hypidiomorphic and idiomorphic *zircons* (measuring up to .2 mm). Both are often concentrated in biotite. *Opaque minerals* were observed in 640 only.

Cordierite-quartzdiorite and related rocks

Accurate mapping of the rocks is impossible because of the dense vegetation and the mode of intrusion: in hollow paths weathered *cordierite-quartzdiorite* was observed as small stocks, thin sills and dykes; together the whole may be best described as a "stockwork" of quartzdiorite in orthogneiss. Contacts with neighbouring rocks are sharp and abrupt where observable.

The colour of the cordierite-quartzdiorite is dark bluish grey in fresh state and brownish grey when weathered. The grainsize is normally under 6 mm. Conspicuous in all samples, especially in the somewhat weathered ones, is the hypidiomorphic to idiomorphic habit of plagioclase (fig. 4 l). Other macroscopically recognizable minerals are muscovite, biotite and bluish grey cordierite. In many cases the rock contains elongated nearly black xenolithic fragments, very rich in biotite (fig. 4 l); sillimanite is often visible in them with the handlens.

Observations made in 10 slides of cordierite-quartzdiorite will be summarized below. The medium-grained rock has a hypidiomorphic inequigranular texture with idiomorphic or hypidiomorphic plagioclase and cordierite embedded in quartz with biotite and muscovite. In the thin sections it is often very difficult to distinguish small quantities of xenolithic material from the quartzdiorite itself, because some constituent minerals of both are the same.

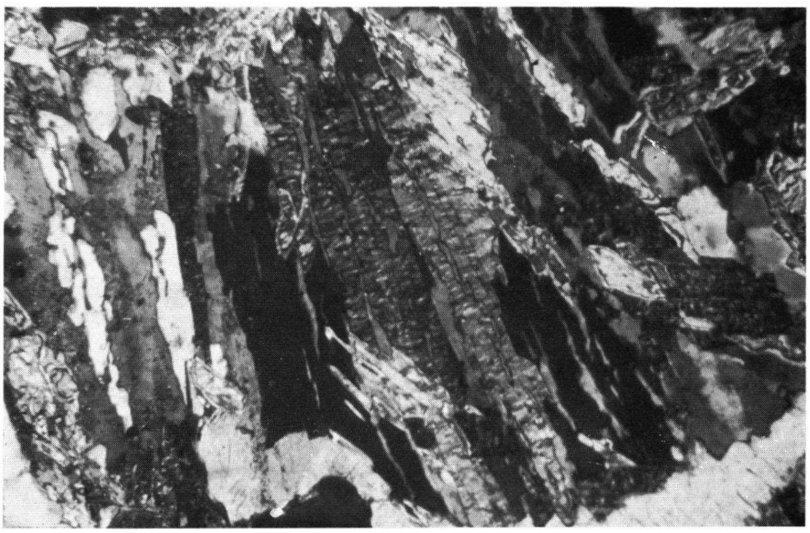


Fig. 6 Implication intergrowth of quartz (black and white), muscovite and acid plagioclase (grey) in cordierite-quartzdiorite (757; crossed nicols, 93 ×).

Stongly undulose crystals of *quartz* with irregular grainboundaries and varying grainsize together with micas fill the spaces around plagioclase and cordierite. In various places optically continuous orientation of quartz over many millimetres was observed.
In all but two samples very irregular coarse implication intergrowths of quartz, muscovite and subordinate xenomorphic plagioclase occur locally in the spaces between idiomorphic plagioclases and cordierites. The quartz in these intergrowths also shows strongly undulose extinction (fig. 6).

The *plagioclases* of the quartzdiorite display a strong tendency towards idiomorphic development with maximum sizes of 3–6 mm (fig. 7, 8). The anorthite content in the normal or oscillatory zoned crystals varies between the extremes of 31 and 2 %. Normally, variations are within the range of oligoclase: 30–10 %. The twinning of these plagioclases is very complicated. Lamellar (010) and (001) twins are common; Carlsbad- and other simple twins were observed in many sections, glide lamellae in two only. In their outer zones the plagioclases enclose many drops and vermicules of myrmekitic quartz, though potassium feldspar is conspicuously absent in most rocks. Alteration products are sericite, carbonate and some muscovite flakes.

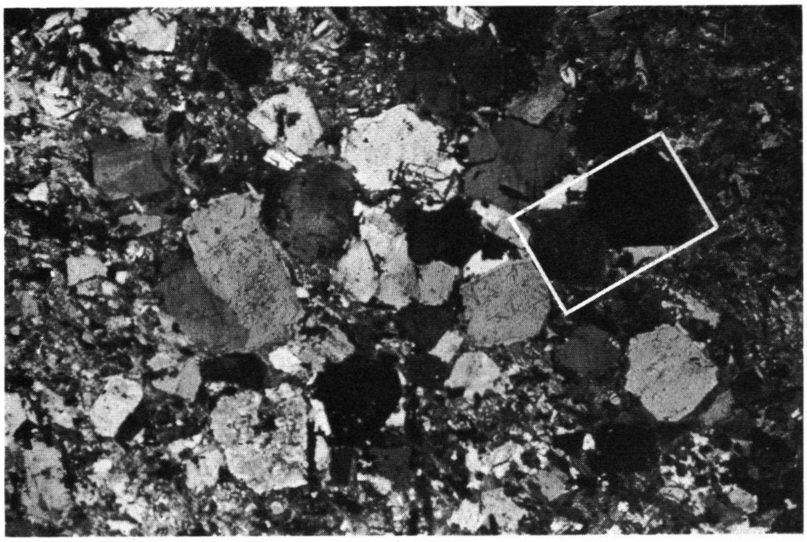


Fig. 7 Hypidiomorphic plagioclases in cordierite-quartzdiorite (756; crossed nicols, 5 ×).

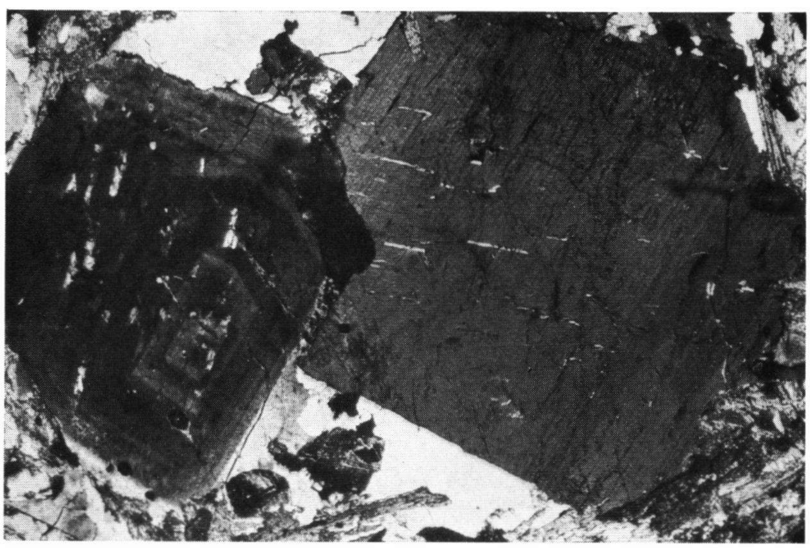


Fig. 8 Detail of fig. 7 (crossed nicols, 25 ×).

In addition to these idiomorphic crystals, plagioclase is also present in a small amount in the implication intergrowths described above and in the xenolithic fragments. The mineral is xenomorphic and lacks the characteristic zoning and twinning. Only in a plagioclase-rich fragment irregular zoning comparable with that in metamorphic rocks has been observed. The composition of the xenomorphic plagioclase mostly falls within the range of oligoclase.

Microcline has been noticed in sample 760 only. Xenomorphic crystals range up to 6 mm. have very fine cross-hatch twinning and sharp, narrow perthite lamellae often optically continuous with plagioclases around the rims of the microclines. The development of myrmekite in plagioclases against these microclines is not more frequent or more pronounced than in the samples without potassium feldspar. In the same specimen plagioclase sometimes encloses small rectangular patches of microcline.

Idiomorphic *cordierite* with pseudo-hexagonal twinning and lengths up to 3.5 mm is a major constituent in 7 of the 10 investigated samples (fig. 9). In a few cases idiomorphic

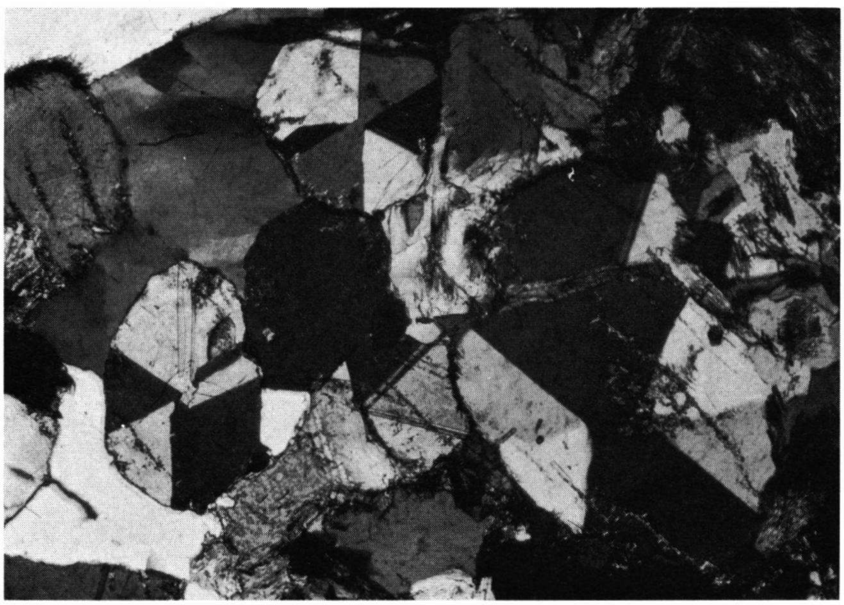


Fig. 9 Hypidiomorphic cordierites in cordierite-quartzdiorite (755; crossed nicols, 50 ×).

cordierite occurs within idiomorphic plagioclase. The mineral shows only incipient alteration into pinite, recognizable sericite or muscovite. In four thin sections sillimanite is enclosed by cordierite. Around radioactive minerals dark yellow pleochroic haloes have developed.

Dense aggregates of fibrolitic *sillimanite* were noticed locally around cordierite and plagioclase. The rims of these masses are often brown and very fine-grained, whereas interior parts consist of somewhat coarser colourless crystals. In four slides the mineral has been observed in cordierite, in four it was enclosed in muscovite and in all sections of rocks with dark fragments it occurs in the biotite-rich masses. In the last-mentioned cases the mineral is present in thicker prisms than elsewhere. One "dark" fragment is constituted almost exclusively of two sillimanite crystals (lengths 8 mm) intergrown with biotite, ore and some andalusite.

Andalusite in small xenomorphic crystals is a rare constituent of dark fragments in two specimens.

Red-to orange-brown *biotite* is a common mineral in all rocks. The flakes are xenomorphic, but in quartz an odd idiomorphic flake was seen. The crystals are generally thinner than those of muscovite and they alter into chlorite. Green biotite has been noted in one thin section.

Sagenite needles are present both in chlorite and in some biotites. Muscovite encloses biotite and *vice versa*. Occasionally, biotite is a component of symplectitic intergrowths.

Large, thick flakes of *muscovite* (up to 3 mm) possess very irregular boundaries and are often even completely symplectitically intergrown with quartz and plagioclase. Parallel inclusions of thin biotite flakes in predominating muscovite were frequently observed, especially in the dark fragments.

Apatite is so abundantly present, that it should be termed a minor constituent rather than an accessory mineral. The mineral generally has an idiomorphic habit. Both thick and thin, long prisms have been noticed. The mineral is frequently associated with zircon and monazite. Pleochroic haloes, often present around apatite in biotite, are actually due to small crystals of the just mentioned radioactive minerals enclosed by or adjacent to apatite.

Idiomorphic and hypidiomorphic *zircons* predominate in the quartzdioritic rocks; in the dark fragments rounded zircons are of frequent occurrence.

In addition to zircon, *monazite* has been determined in most samples. The mineral has a lower refringence than zircon, a feature that is especially cleai when both minerals are in contact with each other.

Opaque ore occurs regularly dispersed throughout the rock.

A few grains of *tourmaline* have been observed in six samples. The colour of the mineral is olive-green to lightbrown.

Some tiny *garnets*, one grain of *corundum* and a few of a green *spinel* were encountered in xenoliths in two samples.

The *xenolithic fragments* have variable constitutions, not one being completely equal to another. The following main compositions have been noticed:

1) xenomorphic plagioclase and quartz with some biotite, small flakes of muscovite and a few garnet grains;
2) same as above but with more biotite and muscovite, and with sillimanite;
3) predominating biotite and muscovite; in addition sillimanite (more often enclosed within muscovite than within biotite) and a few xenomorphic cordierites and plagioclases;
4) much cordierite and biotite plus varying amounts of muscovite and sillimanite;
5) mainly sillimanite with subordinate biotite and in some cases andalusite or cordierite (in one xenolith: sillimanite, biotite, cordierite, quartz, green spinel and corundum).

Opaque ore, apatite and zircon were observed in all fragments.

Of the *granodiorite and granite* only a few fresh samples could be collected (fig. 4 m). Under the microscope thin sections of them in many respects show the same properties and relations of minerals as the quartzdiorites. To avoid repetition, only the differing features will be dealt with below.

Absent are cordierite, sillimanite, andalusite and biotite-rich fragments. Instead of quartz-muscovite-(plagioclase) implication intergrowths, quartz is intergrown in a completely different, but also very irregular way with microcline and muscovite. One microcline shows graphic intergrowth with quartz. The former mineral is present as xenomorphic crystals with vague cross-hatching. In one of the two slides studied narrow perthite lamellae are visible, while in the same section microcline has been partly replaced by albite. Myrmekite is common in outgrowing rims of neighbouring plagioclases. These rims are of albitic composition and show rather abrupt transitions to the (oscillatory) zoned cores with 25–15 % An. Idiomorphic outlines of biotite are more common than in the quartzdiorites, especially in 625.

Pegmatites and pegmaplites

Pegmatites with coarse-grained quartz, feldspars and other possible constituents and *pegmaplites* with coarse parts but also sugary-white fine-grained portions are present almost everywhere in the mapped area. The former have thicknesses generally not exceeding a few decimetres, while it is not possible to follow them over distances of more than a few metres. The latter are much thicker and have been found nearly exclusively along the contacts and north of the coarse-grained equigranular two-mica granite S and W of the Sierra de Galiñeiro. The pegmaplites in that region have thicknesses of metres and lengths of up to more than hundred metres, so it is possible to represent them on the geological map (plate 1). Where they are surrounded by paragneisses they weather less easily than the wall rock and stand about 1 m above the vegetation. Most of them are visible on aerial photographs. All pegmatitic rocks have sharp contacts; the walls of narrow dikes clearly demonstrate that they opened by dilatation. In the pegmaplitic contact of the above-mentioned granite potassium feldspar is being quarried on a small scale at two places on the western slope of the Sierra de Galiñeiro. More to the north the weir of the drinking-water reservoir of Vigo (Embalse de Zamanes) has been built on the place where a thick pegmaplite traverses the valley. This rock has been used for the construction of the dam and there remains an easily accessible quarry in the southern buttress. Xenoliths of paragneiss are not rare in the pegmaplites. In some cases the inclusions or the wall rocks of the dikes are conspicuously enriched in tourmaline.

The mineralogical composition of the *pegmatitic* rocks is variable.
In addition to potassium feldspar, plagioclase and quartz the pegmatites contain either biotite with some muscovite and tourmaline, or muscovite with or without some tourmaline or biotite. Biotite alone has been reported by O. Martinez Rodriguez (oral communication) from a large pegmatite in the coarse-grained biotite granite near Puenteareas, E of the mapped area (fig. 1). No pegmatite has been encountered in the same granite in the area itself. All other rocks of granitic composition are seen to be cut by pegmatites. It is impossible to indicate which granite gave rise to which type of pegmatite.

The *pegmaplites* have a more interesting composition. In the small feldspar quarry on the SW slope of the Zorro considerable quantities of milky-white, intransparent beryl crystals, up to 10 cm across and about 50 cm long have been found, accompanied by colourless mica, small garnets and some tourmaline. Beryl has been reported by Parga-Pondal (Mapa geol. de España, 1953, p. 52) to be present just south of the map area along a forest-road leading to Monte Aloya in pegmaplites cutting the same granite that underlies the above-mentioned beryl pegmaplite. A small crystal of beryl has also been collected in the pegmaplite quarry near the dam site W of Zamanes together with garnets, colourless mica, tourmaline and specimens of pegmaplite with a conspicuous blue colour, due to thin blue coatings on cleavages and grain-boundaries of minerals. In thin sections several rare accessory minerals were encountered. The aplitic parts in this pegmaplite consist almost entirely of tabular albite. A wolframite crystal of 5 cm length is present in a sample from the small quarry on the western slope of Monte Galiñeiro. From the areal distribution of the pegmaplites it may be deduced that they are related with the coarse-grained equigranular two-mica granite. In conclusion it should be remarked that no pegmatites have been observed in the quartzdiorites.

Granite-porphyry

East of the muscovite granite weathered granite-porphyry crops out in a path. No continuation of the dyke has been found. Macroscopically, feldspars up to 4 mm, quartz crystals up to 2 mm and small crystals of a black mineral are surrounded by a yellowish brown aphanitic groundmass.

Under the microscope the quartz appears to be pseudomorphic after high-temperature quartz, slightly corroded and without undulose extinction. Around these crystals quartz of the groundmass, micrographically intergrown with feldspar, has an optical orientation parallel with that of the enclosed phenocryst. Other phenocrysts are idiomorphic potassium feldspars (orthoclase?) with narrow perthite lamellae and Carlsbad twins and idiomorphic plagioclase with polysynthetic twinning on (010). The dark "phenocrysts" prove to consist of aggregates of small green biotite crystals. Like the feldspar of the phenocrysts, that of the groundmass is strongly altered and determination of the components is impossible. The grainsize is generally smaller than .3 mm. Micrographic intergrowth of quartz and feldspar is common.

Tourmaline-bearing rocks

Predominantly around the coarse-grained equigranular two-mica granite, but also in some other localities, rocks with considerable quantities of black tourmaline were noted. They can be divided into two types: tourmaline-quartz veins and tourmaline-rich schists.

Tourmaline-quartz veins have rarely been found in outcrops but often loose along paths and roads, e.g.: at the end of the forest-road on the western slope of the Galiñeiro range. The tourmaline in these rocks has no preferred orientation. Crystals vary greatly in quantity and dimensions: some rocks contain relatively few and thin needles (width 1 mm, length up to 30 mm), others thicker prisms (width up to 6, length up to 20 mm), whereas others again consist almost entirely of tourmaline.

The tourmaline-rich schists owe their content of tourmaline partly to metasomatic influence of muscovite-rich pegmatitic veins: the contact of the two rocks is often formed by a 1–2 cm thick layer of tourmaline crystals penetrating into the schist. More remote from the contact with pegmatite or even beyond the visible presence of any pegmatitic rock at all, schists studded with tourmaline crystals have also been met. As the most extreme example one finds a rock with alternating layers of tourmaline and quartz with some interstitial muscovite and accessory apatite, zircon and ore. The tourmalines contain many inclusions (quartz and opaque minerals mainly), arranged parallel with the schistosity. The muscovite has not been disturbed by the growth of neighbouring tourmalines. More commonly the rocks are two-mica schists with tourmaline crystals lying parallel with the schistosity plane and having some preferred orientation within that plane. In a thin section of such a rock it could be observed that the tourmaline pushed the muscovite aside during its growth. The colour of the mineral is light brown with a greenish tinge; around enclosed grains of radioactive minerals it changes to green.

III. THE RIEBECKITE GNEISSES

FIELD ASPECTS

In the higher parts of their occurrence the riebeckite gneisses are well exposed in vast blocky fields. Unfortunately, the rocks are brittle, often brick-red by alteration so that fresh specimens cannot always be collected. In lower areas the rock is mostly weathered to sandy soil, covered with heather, gorse and pine. Outcrops or loose blocks of gneiss are scattered among the vegetation; the rock may further be studied in paths. Fresh and compact rocks with conchoidal rupture can only be observed and sampled in quarries which are present in several parts of the complex. The most prominent ones are situated on the eastern slope of La Guia and in the ridge immediately west of Vilaverde. The author also collected numerous specimens just south of La Guia, where terrain is being levelled for the construction of harbour facilities and a railway yard. At the time of publication of this paper the exposures in that area will probably have completely disappeared.

The rocks under discussion are mostly fine-grained, well foliated and leucocratic with alternating thin bands of dark and light constituents. At La Guia linear textures locally predominate over planar ones. The foliation is nearly always flat and undisturbed. Foliation microfolded on a centimetre scale has been observed on the summit of La Guia, N of Vilaverde where the inferred fault cuts riebeckite gneiss, and on the eastern slope of San Bartolomé. Bands of gneiss with a somewhat different composition show sharp, nearly isoclinal folds with amplitudes of about 1–2 m. In these cases the foliation itself has not been folded.

As "*normal*" *riebeckite gneisses* two varieties can be distinguished: The *Galiñeiro-type*, with large albites and generally small microclines, occurring everywhere except on the Zorro, S of Monte Galiñeiro, where rocks of the second or *Zorro-type*, with large microclines and less numerous large albites, are found, and at some places in the narrow band between Zamanes and Vigo, where biotite gneisses were collected instead. *Radioactive gneisses* outcropping locally E and NNE of Zamanes, constitute a third type. *Quartz veins*, often folded in the same way as the distinctly composed gneiss bands mentioned above, *pegmatites* and in lesser degree *joints* with overgrowths of riebeckite are not rare within the normal riebeckite gneisses. Contacts with neighbouring paragneiss and biotite-amphibole gneiss are seldom exposed; they even seem preferentially weathered. Where visible, they are sharp. Dip and strike of the foliation of riebeckite gneiss are accordant with the schistosity or foliation of the adjoining rocks. *Marginal facies* of riebeckite gneiss seem to be present along its contacts in several places. Cognate inclusions were never recognized, *xenolithic inclusions* are rare. Along the coast of La Guia and on the slopes of Cepudo and San Bartolomé riebeckite gneiss has been *intruded by two-mica granite*. It is important to note that amphibolite lenses are completely absent within riebeckite gneiss, even where they are numerous immediately beyond its contacts.

The petrography of the rock types listed above will follow after a description of the minerals present in the normal riebeckite gneisses. Minerals differing from those in the normal gneisses will be mentioned in the petrographical sections related to the rocks in which they occur. A discussion of the chemical composition of the riebeckite gneisses concludes the chapter.

MINERALOGY OF THE GALIÑEIRO- AND ZORRO-TYPES

Quartz is present in considerable quantities. Its crystals are slightly undulose and mostly smaller than about .5 mm, though a few larger ones (up to 3 mm) were noted in most thin sections. Small oval or rectangular droplets were seen within larger crystals of microcline. They are arranged in either of two sets of preferred orientations that seem to be related to the crystal structure of the microcline host. Oriented quartz droplets were occasionally observed in albite too. Quartz crystals of rod-shaped cross-section with similar preferred orientations are present in microclines of some rocks belonging to the Zorro-type. Quartz is comparatively free of enclosed minerals.

Albite is generally the largest mineral present. In rocks of the Zorro-type and a few others it is exceeded by microcline. Its crystals are well over 1 mm in diameter and were observed up to 9 mm; they can easily be recognized macroscopically.

The anorthite content, as determined in sections normal to x, α or γ is usually between 0 and 3 % and only sporadically higher (up to 9 %). The outer parts of many crystals have an a few percent higher anorthite content than their cores. The transition between rim and core is abrupt, the boundary line very irregular. Within each zone the anorthite content remains constant. In a few cases two irregular zones were noted, the albite becoming a little more basic in two steps.

Many crystals have an undulose appearance. Closer inspection reveals that this aspect is caused by small differences in orientation of several parts of the crystal upon simultaneous growth from separate nuclei. Several stages in the development of such albite porphyroblasts could be observed. At their rims the crystals often seem to have spread like oil films over the grains of surrounding minerals. Albite encloses all other minerals present in these gneisses.

Though untwinned albites are not rare, twinned crystals were more often met. Simple (010) twins after the albite, albite-Carlsbad and Carlsbad laws predominate; sometimes a central lamella against the composition plane of the simple twin or a relatively broad discontinuous lamella in one of the individuals complicate the picture. One complex twin turned out to be composed of pericline and Manebach, another of albite and Baveno twins, when measured with the universal stage. Not rarely has one of the individuals of a simple twin grown several times larger than the other one. The following could be seen in an albite porphyroblast epitaxically replacing a microcline, which divides the albite – at least in the plane of the section – into two halves: The composition plane of a simple twin is parallel at both sides of the microcline. The individuals of the twin, however, changed their extinction positions: the left individual of the upper part of the porphyroblast has the same extinction as the right one of the lower part, at the other side of the microcline.

TABLE 1 *Albite*

hkl	$2\vartheta_{corr}$			583	584
	583 (WR 836)	584 (WR 837)			
$20\bar{1}$	25.65	25.55			
$1\bar{1}1$	26.85	26.70			
111	27.35	27.25			
130	28.05	27.95	$2\vartheta\ \bar{1}32 - 2\vartheta\ 131$	3.15	3.15
$1\bar{3}0$	28.30	28.15	$2\vartheta\ 111 - 2\vartheta\ 1\bar{1}1$	.50	.55
$2\bar{2}0$	33.00	32.85	$2\vartheta\ 131 - 2\vartheta\ 1\bar{3}1$	1.25	1.25
$1\bar{3}1$	35.10	35.05			
131	36.35	36.30			
$\bar{1}32$	39.50	39.45			

Optic axial angles were measured by Drs. H. Koning with the universal stage in thin sections 583 and 584, the specimens of which were collected at the N foot of hill 658 m. The values obtained vary between 75° and 76°.
X-ray investigation was carried out in the Department of Geology and Mineralogy, Agricultural University, Wageningen, Netherlands, after separation of albite (method described by Doeglas et al., 1965). The results of measurements that yield data for the determination of composition and structural state are listed in table 1. The powder diagram (registration number: Wageningen G 258) was made in a multiple Guinier camera after De Wolff (1948) in Co K_α radiation.
The values of the glancing angles and the differences between specific ones (see table 1) are influenced both by the composition of the plagioclase and by its structural state. Since the microcline in 583 and 584 is a maximum microcline (see below) it is probable that albite is also in its maximum low-temperature state. The same is evidenced by the low value of the measured optic axial angle (Slemmons, 1962; fig. 3). The measured differences point to anorthite percentages of respectively 5, 0 and 2 % (van der Plas, 1966; figs. 57, 58, 59).

In the Galiñeiro-type, *microcline* is mostly found as crystals smaller than 1 mm in granoblastic mosaics together with quartz. In many thin sections they display extremely well-defined cross-hatch twinning. Microscopically detectable perthite is rare in these crystals.
A few larger crystals (up to 4 mm) are present in most thin sections. They may surround grains of other minerals like the albite porphyroblasts and may enclose small microclines with completely different orientations. When the small microclines have very sharp cross-hatching, it was noted that the larger microclines have this twinning less pronounced. A little patch or vein perthite is often visible within them and they enclose a few oval or rectangular quartz droplets in many instances, as described in the section concerning quartz.

TABLE 2 *Microcline 61 Cor. 20*

	Weight %	Chemical composition	
SiO_2	65.34	Or	99.6
Al_2O_3	18.60	Ab	.4
Fe_2O_3	.26	An	.0
MnO	.00		
MgO	.00		
CaO	.00	Analyst: Dr. J. van Schuylenborgh	
Na_2O	.37	Department of Geology, Agricultural University,	
K_2O	15.52	Wageningen, Netherlands.	
H_2O	n.d.		
TiO_2	.00	Optic data	
		α: 1.517 ± .002	
	100.09	β: 1.520 ± .002	$2V_\alpha$: 74°
		γ: 1.524 ± .002	

Selected X-ray data				Cell parameters	
hkl	$2\vartheta_{corr}$	d	I/I_1		
130	23.19	3.833	25	a : 8.581	α : 90.65°
$1\bar{3}0$	24.01	3.703	35	b : 12.96	β : 115.94°
131	29.42	3.033	11	c : 7.223	γ : 87.63°
$1\bar{3}1$	30.24	2.954	18		
400	47.11	1.927	6		

The microclines in the Zorro-type rocks are usually larger than the albite porphyroblasts. Maximum diameters vary between 3 and 7 mm. They have the same properties as the larger microclines in the rocks of Galiñeiro-type. Besides, they sometimes contain the oriented rod-shaped quartz inclusions mentioned in the section about quartz, which were noticed in only one rock of the Galiñeiro-type.
A big block of Galiñeiro-type astrophyllite- and lepidomelane-bearing riebeckite gneiss has been collected S of La Guia for isotopic age determination (61 Cor. 20). The preparation in the Laboratory for Isotope Geology, Amsterdam, of the samples for dating yielded pure concentrates of a.o. microcline, lepidomelane, astrophyllite and riebeckite. Of the first and last mineral, quantities were such that part of them could be used for mineralogical investigation. A detailed optical, chemical and X-ray analysis of the microcline has been made by Dr. L. van der Plas and Drs. J. W. Visser [1]); some results are presented in table 2. The powder pattern was made with a multiple Guinier camera after de Wolff (1948) in Cu K_α radiation.
Values of table 2 demonstrate that the microcline in the investigated riebeckite gneiss, which has not been selected specially for this purpose, is nearly pure, maximum triclinic microcline. Less complete routine measurements on powder patterns of microclines from 583 and 584, separated during the purification of the afore-mentioned albite samples gave the same results.

The crystals of *riebeckite* are xenomorphic to hypidiomorphic. Basal sections tend to be more idiomorphic than longitudinal ones. Often some faces have fully developed, whereas others of the same individual are completely lacking. Poeciloblasts or groups of crystals with parallel optical orientations were also noted. The maximum observed length of the mineral is 2.5 mm, but mostly they are smaller than 1 mm. In a few cases parallel outgrowths of very thin needles upon larger crystals were seen. Stellar aggregates of riebeckite needles occur in one slide.
The colour of the mineral is black in hand specimen and yellowish brown to nearly opaque pleochroic in thin section. The elongation of the basal section (i.e.: the position of the optic axial plane), which serves as a criterion to distinguish between riebeckite (—el) and its variety osannite (+el) (e.g.: Tröger, 1956, p. 68), is generally positive. The elongation of the longitudinal section is always negative. This leads to the conclusion that γ = y and O.A.P. ⊥ (010). The pleochroic scheme of the mineral is: α: very dark blue (sometimes with a greenish tinge); β: yellowish brown; γ: very dark greyish blue. The absorption of α and γ is much stronger than that of β. Basal sections with negative elongations are certainly present in some sections, in one instance together with riebeckites having positive elongations. These riebeckites have the pleochroic scheme: α: veiy dark blue with a greenish tinge; β: very dark greyish blue; γ: yellowish brown; β = y and O.A.P. // (010). Since modern nomenclature discourages the use of the name osannite both minerals are called riebeckites. Both have strong extinction dispersion. Optic axial angles could not be observed or estimated due to the strong absorption of the mineral.
Parallel intergrowths of riebeckite and aegirine were noted in many thin sections. In these intergrowths riebeckite is often surrounded by aegirine. Alteration products are limonite and very fine brownish or greenish micaceous aggregates. Generally, however, the mineral is unaltered.

The riebeckite of 61 Cor. 20 has been selected for more detailed investigation. The chemical composition and optical properties are listed in table 3, X-ray data in table 4. The oxydes of the partial analyses have been weighed with alumina in the complete analysis. The numbers of cations on the basis of 2300 O calculated from the originai analysis and the high total weight percentage of the latter indicate that errors were made, probably in the determination of FeO, total iron and total R_2O_3. To get an idea of the magnitude of these errors, the formula of the amphibole under discussion has been derived from that of Ferro-actinolite, also in water-

[1]) Department of Geology, Agricultural University, Wageningen, Netherlands and Technisch-Physische Dienst T.N.O.-T.H., Delft, Netherlands respectively. A publication by van der Plas & Visser is in preparation on this microcline and other feldspars. Complete data of the microcline under discussion will be incorporated in the A.S.T.M. X-ray powder data file. The investigated specimen bears the registration number: Wageningen WR 807; the X-ray photograph: Delft XX 267.

TABLE 3 *Chemical composition and optic data of riebeckite 61 Cor. 20*

Weight percentages

	Original analysis	Modified analysis 1	Modified analysis 2
SiO_2	48.92	48.92	48.92
Al_2O_3	.37	**2.25**	—
TiO_2	1.41	1.41	1.41
Fe_2O_3	17.24	**18.90**	**22.40**
FeO	21.90	**15.80**	**15.80**
MnO	.67	.67	.67
MgO	.57	.57	.57
Li_2O	.58	.58	.58
CaO	.75	.75	.75
Na_2O	6.10	6.10	6.10
K_2O	.80	.80	.80
H_2O^+	1.82	1.82	1.82
H_2O^-	.44	.44	.44
P_2O_5	.05	.05	.05
F_2	.51	.51	.51
	102.13	99.57	100.82
—O=F	.21	.21	.21
	101.92	99.36	100.61

Numbers of cations on the basis of 2300 O

	Original analysis		Modified analysis 1		Modified analysis 2	
Si	759	800	759	800	759	800
Al	7		**41**		**0**	
Fe^{3+}_{IV}	34		**0**		**41**	
Fe^{3+}_{VI}	167	184	**221**	238	**221**	238
Ti	17		17		17	
Fe	284	341	**205**	262	**205**	262
Mn	8		8		8	
Mg	13		13		13	
Li	36		36		36	
Ca	12	210	12	210	12	210
Na	183		183		183	
K	15		15		15	

Analyst: Mrs. H. M. I. Bult-Bik

Partial analyses (weight percentages)

ZrO_2	.03
Nb_2O_5	.065
Ta_2O_5	< .02

Analyzed by: Analytical Laboratory,
N. V. Hollandse Metallurgische Industrie Billiton, Arnhem

α' : 1.697 ± .002
γ' : 1.706 ± .002
measured in sodium light

$\gamma = y$; $c \wedge \alpha$ small

Pleochroism: α: very dark blue
β: yellowish brown $\alpha \approx \gamma > \beta$
γ: very dark greyish blue

free notation: $Ca_{200}\ Fe^{2+}_{500}\ Si_{800}\ O_{2300}$ using subsequently the following substitutions (and tacitly assuming that the percentages of the other oxydes were determined exactly!): 188 (Na, K) Fe^{3+} for 188CaFe^{2+}; 41Na(Al, Fe^{3+}) for 41Si (Na occupies vacant position); 17Ti for 17NaFe^{3+} (Na from vacant position); 36LiFe^{3+} for 72Fe^{2+} and 14Fe^{3+} for 14 NaFe^{2+} (Na from vacant position). By finally replacing part of Fe^{2+} by the analyzed numbers of Mn and Mg cations the following formula is obtained:

$$(Na_{183}\ K_{15}\ Ca_{12})_{210}\ (Li_{36}\ Mn_8\ Mg_{13}\ Fe^{2+}_{205})_{262}\ (Fe^{3+}_{221}\ Ti_{17})_{238}\ [Si_{759}\ (Al, Fe^{3+})_{41}]_{800}\ O_{2300}.$$

Since the aim of the whole modification procedure was to find the numbers of the cations Al, Fe^{3+} and Fe^{2+} that would fit into the formula, it remains impossible to establish the ratio Al:Fe^{3+} in four-coordinated position; the two extremes: only alumina or only trivalent iron completing the silica chains, are therefore listed in table 3 (as modified analyses 1 and 2 respectively). Colville & Gibbs (1964) concluded from a refined structure determination of riebeckite (from pegmatite, Hurricane Mountain, New Hampshire, U.S.A.; Gibbs, personal communication) that little Fe^{3+} replaces Si in tetrahedral coordination. If this may be applied in a more general sense to other riebeckites than the one investigated by these authors, a composition approaching that of modified analysis 1 (table 3) would be more likely.
The results of this analysis, both in its original and in its recalculated state, are considered by the author as a sufficient indication that the alkali amphibile of 61 Cor. 20 is chemically near to the riebeckite composition: $Na_2 Fe_3^{2+} Fe_2^{3+} Si_8 O_{23} . H_2O$ and not to the composition of arfvedsonite, either in the notation of Miyashiro: $Na_2 Ca_{.5} Fe_{3.5}^{2+} Fe_{1.5}^{3+} Si_{7.5} Al_{.5} O_{23}. H_2O$ or in that of Sundius: $Na_3 Fe_4^{2+} Fe^{3+} Si_8 O_{23} . H_2O$ (as quoted by e.g. Deer, Howie and Zussmann, 1963, vol. 2). It is not certain, of course, that the alkali amphiboles in other riebeckite gneisses are chemically also riebeckites. As long as no more analyses are available the name riebeckite will be used for the mineral in all rocks that contain alkali amphiboles with optical properties as described above.
The Li_2O and ZrO_2 contents of riebeckites from the studied area and of occurrences quoted in the literature are given in tables 10 and 12 respectively. A discussion of the lithium content follows in the section petrochemistry of this chapter, while the implications of the quantities of zirconium present in riebeckite will be discussed in chapter IX.
The X-ray diffraction data were obtained with a multiple Guinier camera after de Wolff (1948), using alum as a standard and Cu K_α radiation (registration number W 3362).

Like riebeckite, *aegirine* is present as xenomorphic or hypidiomorphic crystals, generally smaller than those of the former mineral (max. .75 mm). In the specimen it has a colour varying from bright green to nearly black; under the microscope its colour is variable per specimen. Some slides contain very light green, hardly pleochroic aegirines, whereas in others it is bright green with pleochroism: α: green; β: yellowish green; γ: greenish yellow. When crystals are coloured they are also locally bleached, often where they are in contact with riebeckite. No differences in optical properties could be detected between normally coloured and bleached parts of crystals. In rocks containing riebeckite and aegirine greenish blue riebeckite is often accompanied by rather dark-coloured aegirine. This assemblage is relatively common in rocks of the Zorro-type.
The chemical composition and refractive indices of a light-coloured aegirine from riebeckite-bearing aegirine-gneiss (583) are given in table 5. It should be remarked that the aegirine under discussion (with 97 % of acmite end-member molecule according to the chemical analysis) seems to contain only .88 Fe^{3+} ion per formula unit and 82 % of acmite when their refractive indices and corresponding birefringence are plotted on the graphs of Deer, Howie and Zussman, 1963, vol. 2, p. 87 and Tröger, 1956, p. 64 respectively. The oxydes of the partial analyses have been weighed with alumina in the complete analysis. The lithium and zirconium contents of aegirine are to be found in tables 10 and 12.
The X-ray diffraction data (table 6) were measured on a powder photograph (W 3427) taken with a multiple Guinier camera after de Wolff (1948) in Cu K_α radiation.
Alteration into limonite has often proceeded further than that of riebeckite. Micaceous minerals were found as alteration products in one section only.

Lepidomelane is nearly always present as an accessory mineral (small somewhat rounded grains enclosed within albite); it is named lepidomelane because of its striking similarity to optically and chemically investigated trioctahedral mica from a marginal facies gneiss, dealt with below. Only in a limited number of rocks it is a major constituent, occurring as xenomorphic flakes up to 1 mm. Macroscopically, lepidomelane is black or dark brown, in thin section it is brown with pleochroism: α: bright orange-brown; β, γ: nearly opaque (in sections subparallel to (001) not rarely very dark green). The mineral is more often biaxal with a small $2V_\alpha$ than uniaxial. Alteration into brown biotite with pleochroism: α: yellow-brown; β, γ: very dark brown has been observed in two specimens. This biotite may occur in parallel intergrowth with unaltered lepidomelane and may contain some lenses of opaque ore.

TABLE 4 *X-ray diffraction data of riebeckite 61 Cor. 20*

hkl	$\sin^2\vartheta_{obs.}$	$\sin^2\vartheta_{calc.}$	$d_{obs.}$ (Å)	I
020	.007298	.007287	9.02	w b
110	.008419	.008367	8.39	vs b
$11\bar{1}$	.02476	.02477	4.89	m
040	.02922	.02915	4.51	s
$13\bar{1}$	.03941	.03935	3.88	m
$22\bar{1}$	.04412	.04422	3.67	vw
131	.05068	.05066	3.42	s
041	.05120	.05121	3.40	vw
240	.05537	.05533	3.27	m
310	.06073	.06073	3.13	s
$31\bar{1}$ } 221 }	.06689	{ .06582 { .06685	2.98	w
330	.07533	.07531	2.81	w
151 } $33\bar{1}$ }	.07981	{ .07981 { .08040	2.73	vs
$11\bar{2}$	.08535	.08531	2.64	w
061	.08764	.08765	2.60	s
002	.08871	.08826	2.59	vw
260 } $20\bar{2}$ }	.09159	{ .09177 { .09181	2.54	vs
022	.09582	.09554	2.49	vw
400	.10454	.10473	2.38	vw
112	.10791	.10794	2.34	vw
$\bar{3}51$	.10945	.10955	2.33	s
420 } $\bar{1}71$ }	.11220	{ .11202 { .11222	2.30	vw
331 } $31\bar{2}$ }	.11473	.11435 .11504	2.27	s
$24\bar{2}$	.12072	.12096	2.22	vw
171	.12343	.12354	2.19	w
261	.12525	.12515	2.18	s
$15\bar{2}$	.12914	.12903	2.14	vw
202	.13709	.13707	2.08	m
351	.14356	.14349	2.03	m
242	.16606	.16622	1.89	vw
$19\bar{1}$	.17029	.17052	1.87	m
191	.18199	.18183	1.81	m

Cell parameters:

$a = 9.796 \pm .003$ Å
$b = 18.046 \pm .005$ Å
$c = 5.335 \pm .001$ Å
$\beta = 103°37' \pm 3'$

TABLE 5 *Chemical composition and optic data of aegirine 583*

Weight percentages		Numbers of cations per 600 O.			End-member percentages
SiO_2	51.64	Si	199	200	
Al_2O_3	.14	Al	1		
TiO_2	.43	Ti	1	101	Hedenbergite: 1 %
Fe_2O_3	33.47	Fe^{3+}	97		Ferrosilite : .5 %
FeO	.70	Fe^{2+}	2		Jadeite : 1 %
MnO	.18	Mn	1		Acmite : 97 %
MgO	.09	Mg	—		rest : .5 %
CaO	.31	Ca	1	98	
Na_2O	13.00	Na	97		
K_2O	tr	K	—		
H_2O	.23				
P_2O_5	.06				
	100.25	Analyst: Mrs. H. M. I. Bult-Bik.			

Partial analyses (weight percentages)
ZrO_2 .135
Nb_2O_5 .036
Ta_2O_5 < .02

Analyzed by: Analytical Laboratory,
N.V. Hollandse Metallurgische Industrie Billiton,
Arnhem

α': 1.766 ± .002
β': 1.802 ± .002 measured in sodium light
γ': 1.817 ± .003

Pleochroism: α: light green
β: light yellowish green $\alpha > \beta > \gamma$
γ: light greenish yellow

TABLE 6 *X-ray diffraction data of aegirine 583*

d (Å)	I (estimated)	d (Å)	I (estimated)
6.39	m	2 10	w
4.45	m	2.04	w
3.62	w	2.02	w
3.36	vw	1.99	w
3.19	w	1.94	w
3.00	vs	1.73	w
2.91	s	1.66	w
2.55	w	1.64	s
2.54	s	1.61	w
2.48	m	1.59	w
2.21	m	1.51	m
2.12	m		

A few flakes of a *colourless mica* were encountered in several riebeckite gneiss samples. The refractive index α', as compared with adjacent quartz grains, appeared to be conspicuously low: α' mica < ε' quartz. Only the lithian micas lepidolite and zinnwaldite have refractive indices α clearly lower than ε of quartz. Another argument in favour of the occurrence of Li-mica instead of muscovite in riebeckite gneiss is the fact that these micas are much poorer in alumina than muscovite, which is therefore not to be expected in such an essentially alumina-undersaturated rock. The quantities of the mineral are too small for separation. In consequence the determination could not be substantiated by X-ray or partial chemical analyses. Ducellier (1963; p. 161) reports the presence of small quantities of colourless mica (presumably lepidolite) in a few specimens of aegirine-riebeckite granite of Sadba (Upper Volta); Upton (1960; p. 79) describes Li-mica as a rare minor constituent in aegirine-riebeckite microgranite of Kûngnât Fjeld, S W Greenland.

The presence of *astrophyllite* in riebeckite gneisses of the area under discussion has been discovered by the present author (Floor, 1961). It was found – fresh or altered and in quantities varying from considerable to a few flakes only (enclosed within albite) – in one third of the approximately 100 riebeckite gneiss samples investigated. The optical properties as far as they bear on astrophyllite in riebeckite gneiss will be briefly summarized.
Macroscopically, the crystals are brown and lath-shaped. The maximum length observed in thin section is 4.5 mm. The mineral is pleochroic with α: orange; β: yellow; γ: lemon-yellow. α is oriented perpendicular to the perfect cleavage plane; β and γ lie within that plane, γ parallel with the longest extension of the crystals. The refractive indices β and γ were measured in sodium light (table 7). The two values of $2V\gamma$ in the same table are averages of observations

TABLE 7 *Optical properties of astrophyllites*

	Vilaverde Floor (1961)	Kaffo Beer (1952)	Teria Beer (1952)	Kigom Greenwood in Beer (1952)	Kûngnât Upton (1960)
γ	1.757 ± .002	1.757	1.755	1.758	1.751
β	1.722 ± .002	1.725	1.724	1.725	1.715
α	—	1.703	1.700	—	1.695
$2V\gamma$	red light 88.4° green light 81.9° (average values)	large	large	—	—

on 14 crystals in several thin sections with the universal stage. X-ray data, additional optical measurements, comparisons with material from Norway and Colorado (U.S.A.) and with the literature are given in the paper mentioned above. The author was not acquainted with the works of Beer (1952) and Upton (1960) on astrophyllite when writing his publication concerning that mineral. They present refractive indices agreeing very well with his data (table 7).
Unfortunately a complete chemical analysis could not yet be made of astrophyllite. The content of ZrO_2 was determined in the Analytical Laboratory of the N.V. Hollandse Metallurgische Industrie Billiton in astrophyllite separated from 61 Cor. 20. The analysis yielded 1.0 % ZrO_2. The analysis of Rb in the course of a Rb-Sr age determination on astrophyllite from the same sample gave 4716 p.p.m. Rb or .52 % Rb_2O. Butler, Bowden and Smith (1962) found 3000 p.p.m. Rb in astrophyllite from a Nigerian astrophyllite-biotite-riebeckite granite (Teria, Amo complex); Hamilton (1964) reports a Rb content of 4500 p.p.m. in astrophyllite from arfvedsonite lujavrite belonging to the Ilimaussaq intrusion, S W Greenland. The Rb values determined in the Spanish mineral corroborate the conclusion of Butler et al. (1962; p. 97) that 'the analytically neglected astrophyllite is a strong Rb seeker'.

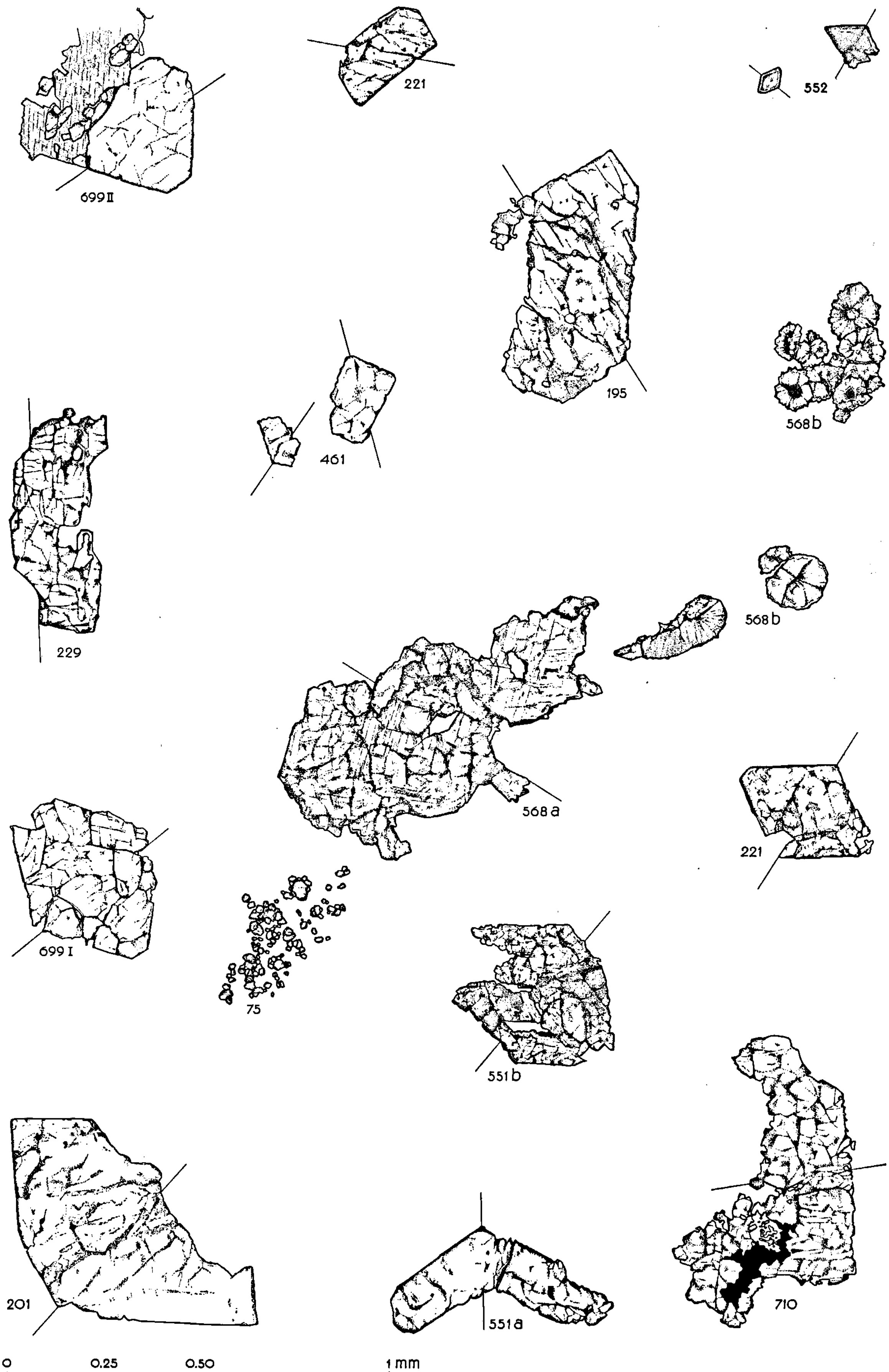
Zircon is never absent in the alkaline gneisses of the investigated area. Its frequency varies from rare accessory to major constituent (in magnetite-zircon gneiss, as a marginal facies, which see). In most cases it is a conspicuous mineral with crystals often exceeding riebeckite and aegirine in dimensions. The largest crystal observed is 1.25 mm across.
The outlines are idiomorphic, hypidiomorphic and xenomorphic. Examples of characteristic outlines are illustrated in fig. 10. Hypidiomorphic crystals, with some nearly perfect faces and others partly or wholly irregular (fig. 10; 195, 201, 229, 551b, 699 I + II, 710) are more common than idiomorphic individuals (fig. 10; 221). Most crystals have peculiar habits because the growth of prism faces has been oppressed in favour of the development of pyramid faces (fig. 10; 201, 461a). Even when one sees a rectangular section the extinction proves that it is actually composed of bipyramid faces (fig. 10; 461a). Obtuse apices of the pyramids (fig. 10; 221, 551a + b, 699 I + II) are more numerous than acute ones (fig. 10; 461a). Basal sections are square or rectangular (fig. 10; 229). The basal plane is not uncommon (fig. 10; 195, 201, 710). Xenomorphic zircons are more variable in size than (hyp)idiomorphic ones, which are seldom very small. The former are found as tiny droplets of .01 mm or even smaller, often clustered together (fig. 10; 75). From these granules they range upwards to irregular individuals with the same dimensions as the (hyp)idiomorphic crystals (fig. 10; 568a). Some rocks contain only clusters of small zircon droplets. Spherulitic development of zircon around a dark coloured nearly isotropic core has been noted in three thin sections (fig. 10; 568b). Pleochroic haloes are hardly visible in riebeckite, lepidomelane or fluorite adjacent to zircon. Four thin sections show examples of intergrowth of zircon and riebeckite. One of these has been drawn (fig. 10; 699II). An interesting feature in the illustrated intergrowth is the continuation of the zircon bipyramid face in the prism face of the riebeckite. The zircons show imperfect cleavage, irregular cracks and contain many inclusions (a.o. opaque matter (fig. 10; 551b). Some crystals are wholly or partly metamict. A zonal distribution of metamict and clear parts has also been observed (fig. 10; 552). Growth zones are occasionally visible (fig. 10; 551b, 568a). The relative ages of zircon will be discussed together with those of other minerals in the next section.

The bipyramidal habit of zircon has been reported several times in the literature. König (1877), in his description of astrophyllite, arfvedsonite and zircon of El Paso Co. (Colorado, U.S.A.), informs that he observed the faces {111}, {110} and {001} [1]. The {110} prism is of minor importance. The otherwise rare basal plane is always present. Brögger (1890) gives numerous examples of zircons with predominantly bipyramidal development in syenite pegmatites of S Norway. Lacroix (1922) produces several drawings of zircons, in which the bipyramidal faces play important roles. It is not clear from his text in which rocks the various types were found. Zerndt (1927) illustrates bipyramidal zircons from a granite. Large bipyramidal zircons are described by Burri (1928) from alkalisyenite-pegmatite, Alter Pedroso, Portugal. Morozewicz (1930) found only pyramidal zircons with a limited presence of the prism face in mariupolites and supposes that this habit is caused by the high alkali content of the rocks. Poldervaart (1956), after a review of zircons in igneous rocks, draws the conclusion that 'apparently bipyramidal habits become common in zircons of more extreme alkaline rocks'. Rocci (1960 a) encountered many 'octahedral zircons' in heavy mineral concentrates from soil samples collected around aegirine- and riebeckite-bearing granites and syenites of the Tabatanat massif, Mauretania. Spotts (1962) gives a photograph of bipyramidal zircon, found as a crystal of rare habit in a mafic inclusion in quartzdiorite of the Coast Ranges (California, U.S.A.). Mano (1963) mentions the discovery of bipyramidal zircons in the biotite-riebeckite granite of Fort-Trinquet (Mauretania) and of zircons with short prism faces or without them in biotite granites associated with aegirine-riebeckite granites of the Tarraouadji massif (Niger). Finally the bipyramidal habit of zircon is cited in recently translated Russian literature. Agafanova (1963) records such zircon in an aegirine-arfvedsonite granite pegmatite (in Malo-Kunaleysk granite complex, Buryat A.S.S.R.). Petrova (1963) observed metamict bipyramidal crystals in aegirine-, riebeckite-, astrophyllite-, etc. -bearing rocks of 'one of the districts of Siberia'. The same author mentions 'crystal intergrowths of radiating forms'.

Fluorite varies still more in quantity than zircon. It is lacking in a few gneisses only.

[1]) Old morphological indices that are related to the cell determined by X-ray analysis by a rotation of 45° around the c-axis.

Fig. 10 Zircons from riebeckite gneiss, as observed in thin sections. The traces of ε have been indicated for individual grains.



699 II
221
552
195
461
568 b
229
568 b
568 a
221
699 I
75
551 b
201
551 a
710
0
0.25
0.50
1 mm

When rare it is seen as small ellipsoid grains enclosed within albite or quartz. With increasing quantities the mineral is not longer enclosed only; patches with irregular outlines appear between the other minerals of the rock. The largest occurrence seen is that of a cluster of irregular grains totalling 8 mm in longest diameter. Quite often fluorite is seen in association with the dark minerals of the gneisses. Against radioactive minerals (not zircon) it is coloured deep purple.

Opaque minerals and in many cases *limonite* are varying in quantity, like zircon and fluorite, though hardly ever lacking. Some marginal gneisses (treated in the relevant section) contain magnetite as a major constituent; there are transitional types between magnetite gneisses and riebeckite gneisses of the Galiñeiro-type. The identity of the opaque minerals in the Galiñeiro- and Zorro-type riebeckite gneisses has not been established and it is possible that other minerals than magnetite are present as well. Idiomorphic, hypidiomorphic and xenomorphic (irregular,

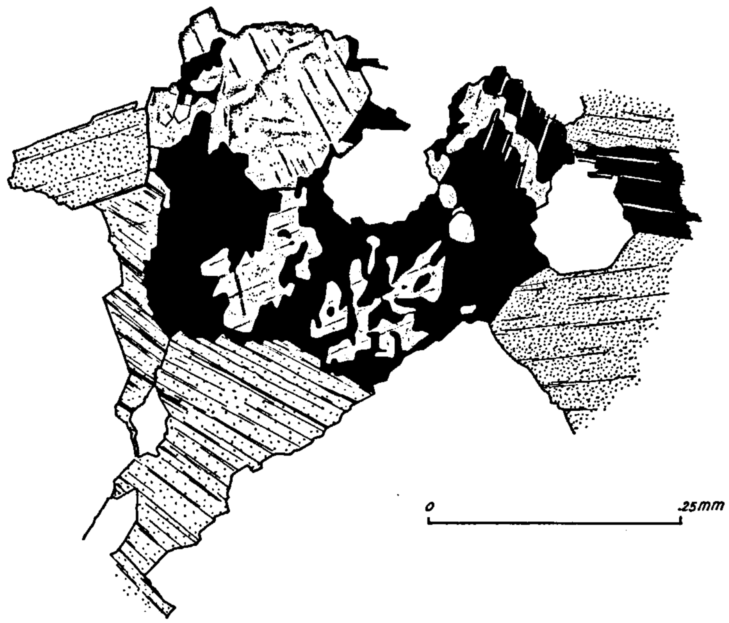


Fig. 11 Replacement of riebeckite (black) by siderite. Lepidomelane is dotted (710)

amoeboid, skeleton-like, etc.) grains were noted. The maximum diameter observed is .5 mm.

Xenomorphic grains of *xenotime* (up to .8 mm, but generally much smaller) were recorded in two thirds of the investigated thin sections. It is often associated especially with opaque ore, zircon and fluorite. Outgrowths upon zircon are common, which may be influenced by the isostructural relationship of both minerals. A brown rim has occasionally been observed to surround the mineral under discussion. The fine-grained reaction product around apatite (which see) is thought to be at least partly xenotime.

The minerals described so far were of rather general occurrence. Those to be mentioned below are rarer, though not less characteristic.

Of *pyrochlore* only a few crystals per thin section were noticed in about one quarter of the investigated samples. The xenomorphic grains or aggregates of same reach maximum diameters of .6 mm but are generally smaller. The colour in thin section is yellow or brown. The mineral causes pleochroic haloes in riebeckite. The determination has been confirmed by an X-ray powder pattern (M 2961).

Apatite was found in one eighth of the slides studied, no more than a few grains per slide. The largest diameter observed is .3 mm. The birefringence is stronger than usual in apatite resulting in light grey interference colours. In a majority of the occurrences it is surrounded by material with higher refractive indices and stronger birefringence showing a uniaxial positive interference figure. Mostly this material is fibrous and fine-grained. In two thin sections it is coarser in grain and could be identified as xenotime. The finer aggregates probably consist of the same mineral.

Seven thin sections of gneisses from La Guia and one from the north slope of Monte Galiñeiro contain small amounts of *siderite*. It is found, like fluorite, as very irregular crystals along grain boundaries of light minerals and associated with riebeckite and biotite. In a few cases it seems to replace riebeckite (fig. 11). Siderite is locally somewhat altered into limonite.

Minerals, tentatively identified as *allanite* were seen in eleven thin sections. The majority has a light yellowish brown colour and weak pleochroism but a few are much darker with pleochroic colours varying between reddish brown and nearly opaque. They resemble the minerals in the radioactive gneisses that could be proved to be allanites by X-ray identification. In two slides dark-coloured allanite forms part of a rim around light allanite. The light-coloured allanite causes clear pleochroic haloes in adjacent riebeckites and deep purple colours in fluorite.

Some grains of *titanite* associated with opaque mineral, occur in one slide. In another, crystals of a mineral resembling zircon but with lower refractive indices were noted; it is probably *monazite*. Sections favourable for inspection of the interference figure are not present.

In quite a few slides mineral grains had to be left unidentified.

PETROGRAPHY

Galiñeiro-type

The distribution of rocks of the Galiñeiro-type and their macroscopical aspects have been discussed in the introductory paragraph of this chapter. Their mineralogy passed in review in the preceding section. Since the gneisses have a rather homogeneous textural appearance it was considered unnecessary to describe separate specimens. Illustrations of planar and micro-folded Galiñeiro-type gneisses are given in fig. 12a, b.

Quartz, albite and microcline are generally present in quantities varying between 25 % and 35 % each. The dark constituents (riebeckite, aegirine, lepidomelane and astrophyllite in variable proportions) together make up between five and ten per cent of the rock.

In thin section the gneisses show inequigranular granoblastic fabrics with large oval or irregular-shaped albites (mostly > 2 mm) embedded in a mosaic of quartz and microcline (usually $< .5$–1 mm). A few adjacent microcline grains may have parallel orientations. Only a few specimens have smaller albites and are consequently less inequigranular. The shape and arrangement of quartz often give rise to a gneissic texture. The quartz may be more or less elongate and arranged in bands (continuous or discontinuous). In other rocks it does not form "trains", the elongate grains lying individually among the feldspars. Rocks in which albite has its longest grain diameter parallel with the gneissic texture are less numerous than those in which albite seems to have grown completely free. The gneissic texture of the light constituents was not seen in about one quarter of the samples investigated. This may be partly due to the fact that sections were made perpendicular to the lineation in linear samples, but there are certainly also rocks in which the absence is genuine. The granoblastic fabric is more regularly developed in these rocks. A few crystals of quartz or microcline with larger dimensions than those of the mosaics are usually seen. Quartz may range upwards to 3 mm, microclines to 4 mm. Rocks found on and around hill 658 m are less strongly foliated than elsewhere and relatively rich in large microclines, though never so much that they are difficult to distinguish from Zorro-type gneisses.

Albites not rarely enclose quartz crystals with an arrangement parallel to that of the quartz bands outside the albites. Recrystallized zones of granulation were noted in a few slides. An important blastomylonitic zone several metres wide was found in the col between Monte Galiñeiro and Zorro.

The dark constituents generally causing a conspicuous foliation or, in some rocks of La Guia, a linear texture, do not give evidence of having undergone any cataclasis. Often the preva-

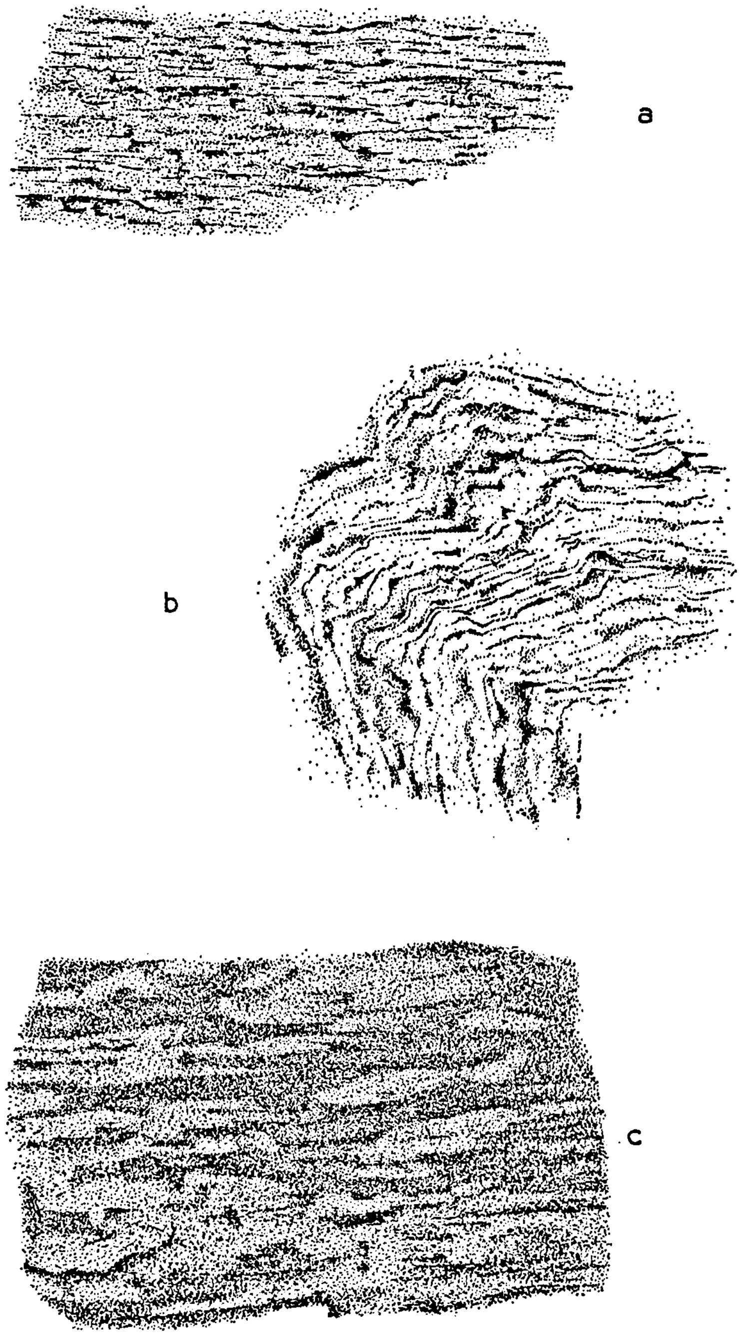


Fig. 12 a: Galiñeiro-type riebeckite gneiss (216A); b: microfolded Galiñeiro-type riebeckite gneiss (197); c: Zorro-type riebeckite gneiss (271). Natural size.

lence of basal sections demonstrates that the crystals possess a preferred orientation. The arrangement in bands turns out to be less conspicuous in thin section than would be suspected when examining the hand specimen. Groups of larger crystals are to be found outside rather than inside the albite porphyroblasts.
The proportions of riebeckite, aegirine and lepidomelane vary strongly. Riebeckite is lacking in one gneiss (in 200 aegirine is the only dark mineral); in all other rocks it is represented, though sometimes in minor amounts than aegirine or lepidomelane. The latter two minerals seem to associate less easily than either of them with riebeckite: gneisses with abundant aegirine and lepidomelane were not found. Small amounts, however, were noted in most thin

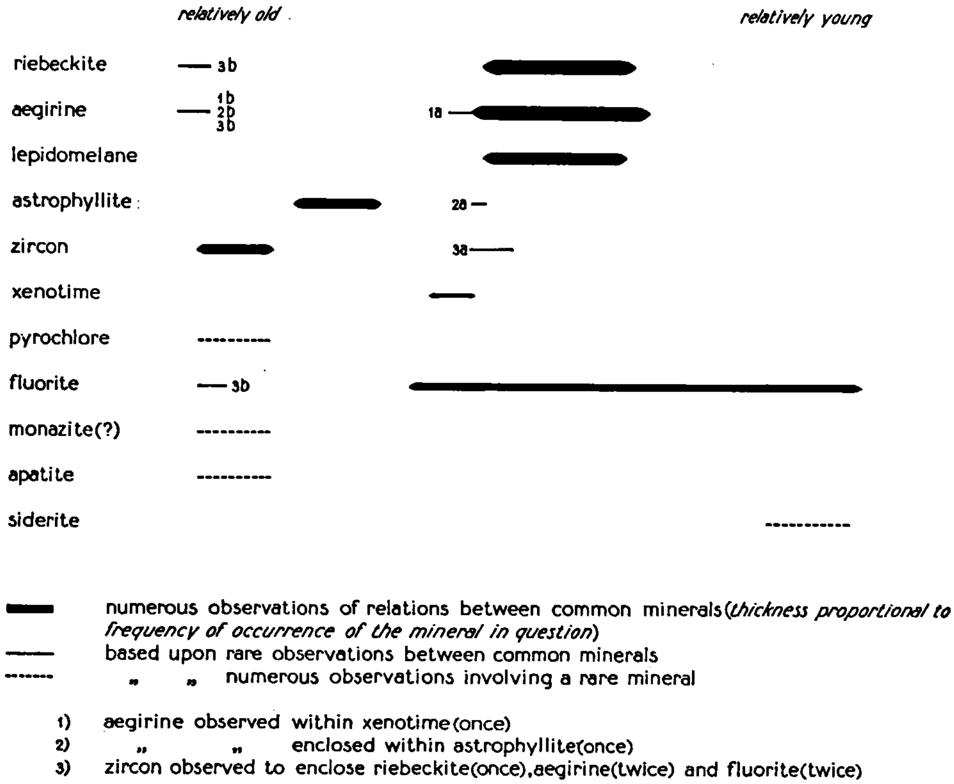


Fig. 13 Age relations of dark minerals and accessories in riebeckite gneiss. Explanation in text.

sections; often a few tiny grains enclosed within albite are the only vestiges. In the hand specimen lepidomelane may resemble astrophyllite but mostly it is easily recognized because of its darker colour. The flakes do not always lie parallel with the foliation. This feature is even more typical of astrophyllite, which mineral nearly always grew in directions oblique to that of the foliation. Radiating aggregates were noted in a few cases. The mineral is commoner in riebeckite or aegirine-riebeckite gneisses than in rocks that carry lepidomelane in more than accessory quantities. One of the exceptions happens to be 61 Cor. 20, an astrophyllite- and lepidomelane-bearing riebeckite gneiss.

In a few specimens certain zones consist almost uniquely of oval albites surrounded by dark constituents (preferentially riebeckite). These zones are always relatively enriched in fluorite. Outside the zones microcline-quartz mosaics and aegirine predominate. On the ridge W of Vilaverde a dark-coloured portion of more than hand specimen-size proved to contain much albite, little microcline and quartz and relatively large quantities of dark constituents (riebeckite, aegirine and lepidomelane together!).

A hematite-rich gneiss, carrying only riebeckite aggregates with a relict-like appearance has been collected in the col between Monte Galiñeiro and Zorro. Riebeckite seems to have been replaced by hematite and quartz in this special case.

The age relations between quartz, microcline and albite, already mentioned in the mineralogical description of these minerals, do not present a completely clear picture. Albite seems younger than the quartz-microcline mosaic since it encloses quartz in "trains"; some patches of enclosed microcline were also observed. The large microclines surround smaller crystals of the same mineral, which suggests a later growth. Unfortunately relations between albite porphyroblasts and larger microclines could not be deduced in thin sections of Galiñeiro-type gneisses.

Observations of minerals enclosing others give an impression of the age relations between dark constituents among each other and between them and the accessories. It has been attempted to visualize the obtained data in fig. 13. It should be borne in mind that rare observations of a certain relation between common minerals present less conclusive evidence than the same number of observations of a relation between a common mineral and an accessory, the chance to see such a relation being smaller. Several ambiguities could not be definitively solved: when xenotime encloses aegirine it can mean that aegirine was crystallizing at the same time as xenotime (possibility 1a, see fig. 13) or that it already existed (1b). The same holds true for the observation of aegirine within astrophyllite. Possibility 2a supposes a two-stage growth of astrophyllite (which should be actually also visible from relations with riebeckite and this is not the case!), whereas 2b assumes the existence of two generations of aegirine. The relations between zircon and riebeckite, aegirine and fluorite suggest either the existence of two crystallization periods of zircon (3a) or two of riebeckite, aegirine and fluorite (3b).

As already stated, larger crystals of the dark constituents were found less inside than outside the albites. The latter minerals, however, usually enclose small crystals to tiny droplets of riebeckite, aegirine, lepidomelane, astrophyllite, fluorite, zircon etc. Microcline is conspicuously free of enclosed dark and accessory minerals in part of the samples, but is studded with them in others. Quartz is practically inclusion-free. These data are considered too scanty to permit conclusions about the age relations between dark and light constituents.

Zorro-type

In the following paragraphs only differences with Galiñeiro-type rocks will be commented upon. Mineralogical data were already given in the section mineralogy.

The gneisses are even more irregular in grainsize than the Galiñeiro-type gneisses. The main differences with the latter are: coarser microcline, often in greater quantities, smaller albites, in microcline-rich rocks in smaller quantities, and coarser quartz in irregular bands or aggregates. Consequently, the rocks do not show the finely banded texture so clearly (fig. 12c). Often the dark constituents are not even concentrated in bands but rather in patchy aggregates, which renders recognition of foliation in the hand specimen rather difficult. About the same difference in texture as between Galiñeiro- and Zorro-type will be described between types of gneisses of the northeastern orthogneiss complex (chapter VI, groups I and II). Macroscopically evident porphyroclasts, however, are very rare in the gneisses under discussion.

The very sharp cross-hatch twinning has not been observed in microclines of this rock-type, in the larger crystals even less than in the smaller ones. The former, usually up to 5 mm across, were seen to display abrupt changes in character of the cross-hatching, are twinned after the Carlsbad law, and contain small quantities of fine vein and patch perthite, quartz droplets and quartz rods (see quartz, in section mineralogy). Some quartz rods were occasionally noted in albite adjacent to microcline enclosing them. The rods in albite have the same optical orientation as those within microcline, also when albite and microcline have distinct crystallographical orientations. The larger microclines are often undulose and fractured. Small microcline and albite crystals line the fractures.

Albite attains diameters of 3.5 mm. It is often less homogeneous than in Galiñeiro-type gneisses:

blastic aggregates of subparallelly oriented patches. As stated above albite was found also as perthite and around large microclines. Quartz measures up to 3 mm, i.e. not larger than in Galiñeiro-type rocks, but in this type a large part of the crystals in the irregular bands and aggregates is fairly coarse, whereas in the former case only a few are relatively large.

The dark constituents (riebeckite often greenish blue, aegirine often dark green) are mainly concentrated in finer-grained quartz-feldspar mosaics between the coarse feldspars and quartz.

The fabric of most gneisses of this type is more blasto-cataclastic than that of the granoblastic Galiñeiro-type rocks. In a few cases real porphyroclasts could be observed: in 839, for instance, quartz bands clearly bend around a microcline crystal, about 1 cm across; a stress shadow of quartz is present and the crystal has ruptured in a direction perpendicular to that of the foliation.

Two features deserve special mention: in 557 a thin band very rich in zircon is macroscopically visible. The band has a direction oblique to the foliation of the specimen. Study of the thin section revealed that zircon is the only mineral causing the band; there is no question of a narrow vein with other minerals and zircons.

363 and 364 contain thin bands of a fine-grained astrophyllite- and aegirine-bearing riebeckite gneiss in Zorro-type gneiss. The bands are nearly isoclinally folded with the axial plane parallel to the foliation of the gneiss (fig. 14). The amounts of microcline are much smaller in the bands than in the surrounding rock.

The age relations of dark and accessory constituents are the same as in Galiñeiro-type rocks. The zircons of the band in 557 give evidence of a post-deformational crystallization period of zircon. The relations of the light minerals present many difficulties. Albite seems again to be the latest crystallization product, which grew after cataclasis and recrystallization. The problem of the order of crystallization of both types of riebeckite gneiss will be further discussed in chapter IX.

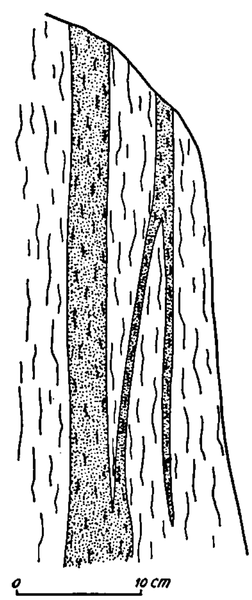


Fig. 14 Shear-folded bands of fine-grained riebeckite gneiss in Zorro-type riebeckite gneiss. Outcrop on NW slope of Mt Zorro. Schematical drawing.

Radioactive gneiss

Gneiss with a high content of allanite and zircon was found at two localities. One is situated N of Zamanes, in the southern extremity of the riebeckite gneiss band La Guia-Zamanes.

The other occurrence is to be found 350 m due south of the chapel of San Colmado, E of Zamanes. It has been studied by the Spanish Geological Survey (Inst. Geol. Min. España, 1959) which produced a radiometric map (fig. 15) and performed three exploration drillings of 25 m depth each. The collected specimens were investigated in the mineralogical laboratory of the nuclear energy commission (Junta de Energía Nuclear) by Arribas (1963) who found low values of U_3O_8 (about .01 %) but quantities of ZrO_2, Y_2O_3, Nb_2O_5, Ce_2O_3, La_2O_3 in the proximity of or superior to 1 %. Arribas' description of the gneiss will be briefly summarized below: Macroscopically the gneissic texture is hardly visible. Fresh rocks are dark grey, weathered ones yellowish grey. In thin section it is grano-lepidoblastic without a marked foliation. Quartz is undulose, xenomorphic and present in variable amounts. Albite is twinned after albite and albite-Ala laws, contains 7 % An and encloses tiny grains of zircon and biotite. Microcline is scarce. The xenomorphic crystals show cross-hatch twinning. Biotite encloses some grains of zircon or apatite. The flakes are small and more or less oriented. Allanite is xenomorphic, and mostly associated with biotite and zircon. The mineral has high refringence and strong pleochroism (dark brown-light brown). Aggregates of very small xenomorphic zircons are irregularly distributed throughout the rock and enclosed by other minerals.

Xenotime resembles zircon but is idiomorphic and has lower refractive indices. It is so common in some rocks that Y_2O_3 determinations yielded values up to 4 %. A few xenomorphic grains of fluorite, very scarce apatite, relatively much magnetite and ilmenite, associated with biotite and allanite and a few isotropic yellow crystals of probably pyrochlore are other accessory minerals. The average modal composition determined from measurements of several samples is:

Albite	46 %	
Microcline	5 %	
Quartz	24 %	(but strongly variable)
Biotite	14 %	
Allanite, Zircon, Xenotime	11 %	
	100 %	

The present author can provide a few supplementary observations made in thin sections of specimens from quarry 2 (fig. 15). The rocks are very inequigranular. Albite is mostly smaller than 1 mm but a few crystals reach 2 mm. Quartz rarely exceeds 1 mm. The dark and accessory constituents are arranged in bands that bring about the foliated texture. Individual crystals do not show preferred orientation. The anorthite content generally turned out to be lower than 7 %. Often, the crystals consist of subparallel-oriented patches grown together from several nuclei. The same habit of blastic albite is present in Zorro-type riebeckite gneisses and in some amphibole-biotite rocks described in the next chapter. The quantity of microcline is even lower than in Arribas' specimens. In some thin sections the mineral was not found at all. Two biotites were noted in 680, the freshest specimen collected. One is pleochroic from very dark brown (nearly opaque) to brownish yellow and is uniaxially negative. The other variety, less common than the first, has $2V_\alpha \pm 20°$ and pleochroism: red-brown to very light brown. In other specimens the latter variety is absent. An amphibole with weak pleochroism in light greyish brown tinges and a very large negative optic axial angle was found in all thin sections. Around radioactive minerals it has reddish brown pleochroic haloes. Twinning is frequent. The mineral alters into fibrous green biotite and limonite. An X-ray powder diagram (M 3339) proved this amphibole to be grunerite. Allanite has pleochroism from chestnut-brown to nearly opaque. It often encloses irregular aggregates of xenotime. Because of the strong absorption optical properties could hardly be determined. An X-ray powder pattern (M 3338) of unheated allanite agreed well with that of allanite from Everard Ranges, South Australia heated to 800° for six hours. No idiomorphic outlines of xenotime were noted in the author's slides. Part of the crysals lies enclosed within allanite. Fluorite is present in considerable amounts. It is deep purple against radioactive minerals (not against zircon.). Apatite is very rare or absent; pyrochlore causes pleochroic haloes in grunerite and biotite. A few minerals could not be identified.

Rocks from the outcrop N of Zamanes have the same mineral content as those cited above, with the only exception that red-brown biotite is lacking. The fabric is less inequigranular and more regularly granoblastic, thus resembling that of the Galiñeiro-type riebeckite gneisses of which these rocks form an extremity. Albite does not occur as patchy individuals but as homogeneous small porphyroblasts; zircon not as aggregates of tiny droplets but as xenomorphic to hypidiomorphic poeciloblastic crystals up to nearly 1 mm. The mineral is occasionally intergrown with allanite. Xenotime crystals in intergrowth with allanite are coarser and have more regular outlines. Pyrochlore is a conspicuous accessory. Two of the five specimens collected contain impregnations with galenite.

It will be interesting to study the composition of the allanite that encloses xenotime. Data in the literature prove that yttrian allanites do exist (Zhirov, Bandurkin and Lavrent'yev, 1961; Neumann and Nilssen, 1962; Mineyev, 1963 and Frondel, 1964). If the allanite in the rock under discussion would indeed prove to be yttrium-rich, the association with xenotime would contradict the conclusion of Zhirov et al. that allanite is yttrium-rich if the rare-earth phosphates monazite and xenotime are absent. The fact that some samples investigated by Arribas contained as much as 4 % of Y_2O_3 may perhaps be an indication that this oxyde is present in important quantities not in xenotime alone.

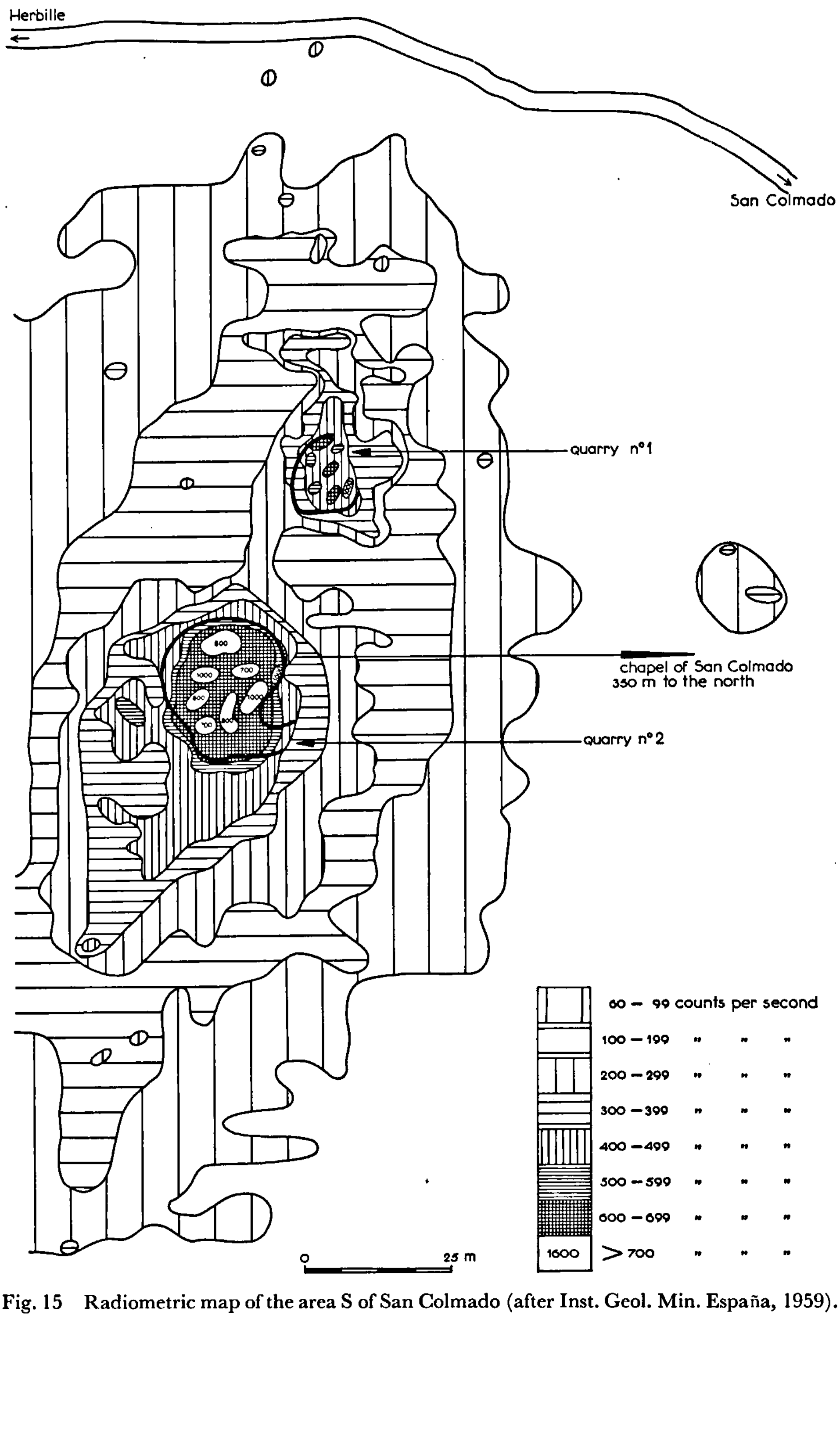


Fig. 15 Radiometric map of the area S of San Colmado (after Inst. Geol. Min. España, 1959).

Quartz veins, pegmatites and mineralized joints

Interesting specimens of riebeckite gneiss with quartz veins, pegmatites and mineralized joints were collected mainly at a few localities, viz. the quarries at the railway yard S of La Guia, the ridge with many small quarries W of Vilaverde and the col between Monte Galiñeiro and Zorro (called henceforth: col 602 m). Most specimens were found as loose blocks, not in outcrop.

Irregular quartz veins are strongly variable in thickness (from a few mm up to several dm) and subparallel to the foliation of the surrounding gneiss. They make the impression of being sheared, though this is not apparent from the arrangement of dark minerals. In some outcrops it could be seen that they are folded isoclinally with amplitudes of a few m (fig. 16).

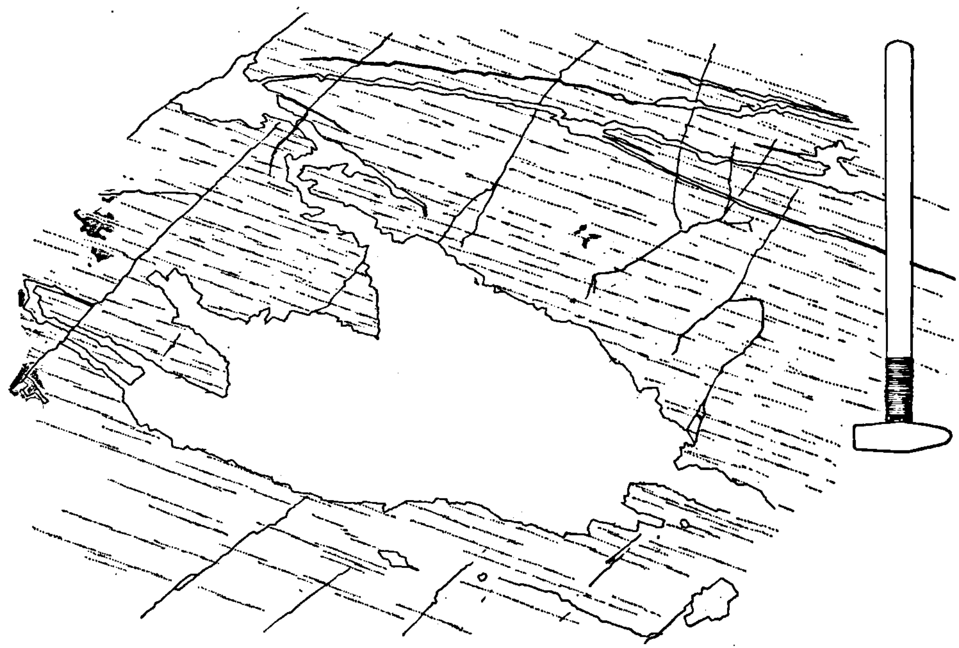


Fig. 16 Shear-folded quartz veins in riebeckite gneiss. Outcrop W of col 602 m.

Quartz veins are extremely numerous. They are either sterile or contain crystals of opaque ore, rutile or feldspar. In a limited number of cases the quantity of other minerals is larger, riebeckite, astrophyllite and rarely aegirine making their appearance. This type of rock will be described in somewhat greater detail:

Usually there is a conspicuous separation of quartz and other minerals, both being concentrated in irregular bands or aggregates. The thickness of the quartz bands may be well over 10 cm. That of the feldspathic portions rarely exceeds 2 cm. Riebeckite and feldspar may attain lengths of 1 cm but are mostly smaller. Riebeckite is either concentrated in patches or evenly distributed between feldspar. Astrophyllite not rarely displays radiating groups of crystals. In thin section 224 the quartz masses are very inequigranular with undulose crystals up to 4 mm and a preferred orientation. The feldspathic parts consist mainly of hypidiomorphic albite (max. 3.5 mm, enclosing quartz grains in the neighbourhood of the quartz bands), of minor amounts of interstitial microcline (with sharp cross-hatching) and quartz. A few crystals of riebeckite and alteration products of astrophyllite are also present.

Irregular pegmatites resemble quartz veins with feldspar and dark minerals, but in this case the latter predominate over quartz. A few loose blocks found on the slopes of col 602 m show crystals of feldspar and riebeckite, more than 1 cm long with minor quartz. Bipyramidal zircons, 1.5 mm across, were noted in one of the samples. Another sample was found in an outcrop at about the same locality, where a 20 cm thick mass consisting of about 50 % riebeckite and 50 % feldspar and quartz is enclosed accordantly within riebeckite gneiss. Part of the quartz is concentrated in a lens of 2 cm thickness.

A thin section was studied of relatively coarse-grained leucocratic irregular bands in lepidomelane-riebeckite gneiss, collected S of La Guia (699II). They are .5–1 cm thick and extremely inequigranular with albite, microcline and strongly undulose quartz (respectively smaller than 2, 3.5 and 2.5 mm) in roughly equal quantities. The microcline is perthitic and has much less well-developed cross-hatching than microcline in the gneissic parts. Of lepidomelane a few strings were seen; riebeckite, though common in the gneiss, is represented by a few grains only.

Other specimens found in the same area contain concentrations of riebeckite, astrophyllite or – in lepidomelane-bearing rocks – lepidomelane.

An astrophyllite pegmatite of col 602 m should be classified as a transitional type between irregular pegmatites and dilatation pegmatites. This pegmatite has been mentioned in an earlier publication concerning the astrophyllite contained in it (Floor, 1961). In outcrop the 10 cm thick pegmatite makes the impression of being clearly discordant with straight boundaries. In thin section the rock turns out to be strongly cataclastic with very much quartz in large inequigranular aggregates consisting of strongly undulose grains (up to 7 mm) with indented grain boundaries and preferred orientations. Of microcline undeformed crystals up to 12 mm were noted, with patch perthite, enclosed albite crystals and sharp cross-hatch twinning. Larger albites (max. 7 mm) have tabular outlines and polysynthetic albite and albite-Carlsbad twins. Not rarely are they bent or broken. Aggregates of more equidimensional grains (< .3 mm) are also present. Astrophyllite in thin and long crystals is common in this rock. It has the following optical properties: γ: 1.758 $\pm$ .002; β: 1.726 $\pm$ .002; $2V\gamma$ averages 78.6° in red light and 67.2° in green light (Floor, 1961). Riebeckite was noted in specimens as crystals of about 1 cm but happened to be lacking in thin sections. Zircon is a common accessory with the same properties as in the Galiñeiro- and Zorro-types of riebeckite gneiss. Xenotime and pyrochlore are present in small quantities, the latter mineral as idiomorphic small grains, enclosed together with small idiomorphic zircons in quartz.

Dilatation pegmatites are clearly discordant and undeformed. The criteria as formulated by Niggli (1953) can be very well applied to them. They are often sterile and composed of quartz and feldspar only, but in other cases small amounts of riebeckite, astrophyllite or (rarely) aegirine were observed. Their thickness may be up to a few dm. Microcline often has a pink colour in these dykes. In thin section weakly perthitic microcline with sharp cross-hatch twinning is the most important constituent. The crystals are large (in the studied sections up to 7 mm); in the remaining spaces mosaics of quartz and a few aggregates of irregular albite were found. Small nearly equidimensional crystals of albite lie enclosed within microcline. A conspicuous feature of the two pegmatites studied (254 and 551, both collected W of Vilaverde) is the presence of large idiomorphic apatites (max. 2.5 mm) with relatively strong birefringence and rims of very fine-grained xenotime. Taking into consideration the scarcity of apatite in the riebeckite gneisses, the dykes appear to be strongly enriched in phosphorus. Astrophyllite, aegirine, zircon and a few separate grains of xenotime were noted too. Riebeckite is the only dark constituent present as larger grains (5 mm in one of the specimens). It encloses apatite and astrophyllite. Apatite encloses astrophyllite and in one instance riebeckite.

Joints covered with overgrowths of mainly riebeckite were found S of La Guia and W of Vilaverde. Especially at the latter locality many valuable specimens have been collected with riebeckite in radiating aggregates of crystals up to 5 cm. Fluorite was noticed in one specimen and feldspar and quartz seem to have grown occasionally as well.

A thin section has been made of a veinlet about perpendicular to the foliation of riebeckite gneiss on the NE slope of Monte Galiñeiro, which is thought to have about the same origin as the mineralized joints. Riebeckite (< .7 mm) is the most important mineral. A concentration of zircon and xenotime (aggregates of small grains, zircon enclosed within xenotime and riebeckite) and a few crystals of opaque ore (up to 1.3 mm) were also observed. The riebeckite of the veinlet is present at both sides of an albite porphyroblast of the gneiss. Along the trace of the veinlet the albite of the porphyroblast has been ıeplaced by microcline.

Irregular quartz veins and pegmatites are older than dilatation pegmatites, which in their turn are older than mineralized joints. These facts could be established in several outcrops and specimens.

Marginal facies of riebeckite gneiss

Several kinds of gneisses, considered as marginal facies of riebeckite gneiss by their position in the field, are represented in the investigated area, either as mappable units or as single outcrops. It is generally impossible to recognize them in the specimen. Two occurrences of marginal gneisses will be found on the geological map (plate 1), viz.: magnetite gneisses, usually with macroscopically recognizable magnetite crystals up to .8 mm, occurring along the inner boundary of the riebeckite gneiss arc between Vilaverde and area N of hill 658 m and biotite gneisses cropping out in the band connecting La Guia with the Galiñeiro area, between Presa and the forest road 750 m south of that locality.

Outcrops of smaller dimensions demonstrate the existence of a large variety of marginal types: biotite gneiss, magnetite gneiss, magnetite-zircon gneiss, leucocratic gneiss, aegirine-augite-bearing magnetite gneiss, pyroxene-bearing bluish green amphibole gneiss and bluish green amphibole-bearing biotite gneiss.

Magnetite gneiss

A gradual transition exists between riebeckite gneiss and magnetite gneiss. Several riebeckite gneisses contain considerable quantities of opaque ore. With diminishing quantities of riebeckite, aegirine or lepidomelane magnetite becomes the most important "dark constituent" and in extreme cases is the only one present. The light minerals and the textures of the magnetite gneisses are very similar to those of Galiñeiro-type riebeckite gneiss. The albite porphyroblasts are finer-grained and may enclose small grains of lepidomelane, pyroxene, amphibole, opaque ore, zircon, fluorite and xenotime; microcline does not display very sharp cross-hatch twinning. The amphiboles in these rocks have greenish blue colours in thin section and are often altered into limonite or micaceous minerals. Lepidomelane when present, is also altered into limonite and a mica with pleochroism: α: yellowish brown; β, γ: very dark brown. Small grains enclosed within albite or quartz are pleochroic from orange-brown to very dark greenish brown (nearly opaque). Pyroxene was only scarcely noted as tiny grains enclosed within quartz or albite. Optical properties could therefore not be determined. The grains have dark green colours. Finally fluorite, xenotime and considerable, though varying, quantities of zircon (mostly clusters of small crystals) were found in all thin sections. A radiating aggregate of zircon has been observed in one slide.

Magnetite gneisses in isolated outcrops were collected in the narrow N-S trending band of riebeckite gneiss SW of Pedra Cavalaria and in an outcrop now concealed by a building in Lavadores. The first contains anatase, the second xenotime associated with very dark coloured allanite in addition to the minerals mentioned above. The albite porphyroblasts are coarser than those of the larger unit to the south.

Biotite gneiss

The biotite gneisses S of Presa are macroscopically very difficult to distinguish from riebeckite gneiss. In thin section the properties and relative proportions of quartz, albite and microcline (without sharp cross-hatch twinning) and the habit of zircon immediately remind the observer of the Galiñeiro-type riebeckite gneisses. The place of alkali amphiboles and pyroxenes is taken here by biotite, pleochroic from yellowish brown (α) to dark brown in two and dark green in one slide (β, γ). Locally the mineral contains small lenses of ore or titanite. A few chlorites occur as alteration products. Albite encloses some small grains of lepidomelane (orange-brown to opaque pleochroitic in one, to dark green in another specimen), greenish blue riebeckite and aegirine. Fluorite, opaque ore, xenotime, apatite and (in one slide) altered allanite are accessory minerals. The rocks closely resemble the leucocratic planar gneisses found E of Zamanes and described in the next chapter.

A contact between biotite gneiss and overlying paragneiss is exposed in a small quarry at the southern entrance of the hamlet of Presa. The specimens collected here will be described separately.

811 was found a few metres under the contact (measured perpendicular to the foliation). Quartz is somewhat larger, albite smaller than in the rocks from the centre of the band; consequently 811 has a distinctly more equigranular appearance with maximum grain diameters of about 2 mm. The quantity of biotite is smaller; as in the preceding cases the unbent flakes are arranged in bands parallel with the foliation and only to a small degree preferentially oriented in the same direction. A few tiny grains of green amphibole are enclosed by quartz. Zircon, fluorite and xenotime are considerably less abundant than in the biotite gneisses described above.

812 comes from the same level as 811, at a place where the rocks are more greyish in colour than the nearly white ones found elsewhere. They are cut by quartz veins up to 1 cm across. In thin section they are again inequigranular with plagioclase up to 3 mm, undulose quartz in discontinuous bands (maximum length of crystals 2.5 mm) and smaller microcline. Plagioclase is partly sericitized, polysynthetically twinned and with a somewhat smaller extinction angle than the rest (limpid untwinned albite). Albite seems to replace the more basic plagioclase, a phenomenon that will be mentioned in subsequent chapters several times. Biotite (brown, green, altered into chlorite with a few grains of epidote), a few grains of garnet and some needles of green amphibole within quartz are the dark constituents. Zircon and fluorite are present rather abundantly, the first as aggregates of tiny grains and as a few larger xenomorphic to hypidiomorphic, partially metamictic and brown crystals. Zircon hardly causes pleochroic haloes in biotite. Titanite, ore, apatite and an uncertain grain of pyrochlore are the accessories.

813 has been taken from just below the contact. Alternating bands can be seen in it with different grain sizes but with the same minerals. The fabric and mineral content differ considerably from those of the biotite gneisses from the main part of the occurrence. Quartz forms discontinuous bands of crystals up to 2 mm. Plagioclase has lamellar (010) and (001) twins, an anorthite content of about 15–20 %, is sericitized and reaches diameters up to 1.5 mm in the coarser bands. Microcline is relatively scarce. Biotite is rather strongly oriented parallel with the foliation and more abundant than in preceding rocks. It has reddish brown colours of β and γ; green biotite, chlorite and a small quantity of muscovite, mostly intergrown with biotite, are also present. Zircon still has the habits common in riebeckite and biotite gneiss: large hypidiomorphic individuals (up to .7 mm) and aggregates of smaller grains. Opaque ore, altered allanite and apatite are other accessories.

815 represents the very contact. The biotite gneiss part resembles the finer-grained variety of 813. Between plagioclase and microcline replacive relations were noted. The contact is sharp. The grain size does not differ much at both sides of it, but the composition of the paragneiss shows some characteristic differences: it is constituted of a mass of plagioclase enclosing quartz and biotite; the amount of biotite is at least twice as large, apatite appears as an accessory, zircons are small and rounded instead of large (up to .6 mm) and hypidiomorphic with bipyramidal habit in the biotite gneissic counterpart. A string of small, irregular-shaped zircons is located in the paragneiss at a distance of about 1.5 mm from the contact. Microcline was sporadically noted, muscovite only as alteration product in plagioclase. The crystals of the latter mineral are predominantly composed of limpid albite enclosing tiny rutile needles and of small quantities of partly sericitized oligoclase showing the same relations as described in 812.

The paragneiss samples 816 and 817, collected respectively 10 cm and 1 m above the contact do not differ sufficiently from 815 to deserve special mention either here or in the relative section of chapter VII.

Biotite gneisses were also encountered N of Marcosende, N of Herbille and N of the chapel of Virgen de las Nieves. The gneisses near Marcosende lie along the northern margin of the riebeckite gneiss band and closely resemble those S of Presa. One thin section contains lepidomelane with the orange-brown to nearly opaque pleochroism observed in the gneisses of Presa only in grains enclosed by albite. Lepidomelane is occasionally slightly bent. A few very small grains of dark green pyroxene were noted in albites in three of four sections studied. Accessories are exactly the same as in the gneisses S of Presa.

The texture and light minerals of 353, forming the western margin of riebeckite gneiss N of Herbille and E of elevation point 421 m, are again identical with those of ordinary riebeckite gneiss.

TABLE 8 *Chemical composition and optic data of lepidomelane 353*

Weight percentages		cations per unit cell		
SiO_2	36.90	Si	6.149	Tetrahedral group 8.000
Al_2O_3	7.58	Al	1.487	
Fe_2O_3	7.26	Fe^{3+}_{IV}	.364	
FeO	32.83			
MnO	.69	Fe^{3+}_{VI}	.546	Octahedral group 5.726
MgO	.56	Ti	.142	
CaO	.11	Fe^{2+}	4.573	
Na_2O	.10	Mn	.095	
K_2O	8.10	Mg	.140	
H_2O	1.89	Li	.230	
TiO_2	1.14			
P_2O_5	.07	Ca	.020	
Li_2O	.34	Na	.030	
F	.60	K	1.721	
	98.17			
—O=F	.25	Analyst: Mrs. H. M. I. Bult-Bik		
	97.92			

Structural formula (half cell)

$$[(\overbrace{}^{+.03}\underbrace{Ti_{.07}\,Fe^{3+}_{.27}\,Fe^{2+}_{2.29}\,Mg_{.07}\,Mn_{.05}\,Li_{.12}}_{2.87})\,(\overbrace{}^{-.92}Si_{3.08}\,Al_{.74}\,Fe^{+}_{.18})\,O_{10}\,(OH)_2]^{-.89}\,(K_{.86}\,Na_{.02}\,\tfrac{1}{2}Ca_{.01})^{+.90}_{.89}$$

β′, γ′: 1.674 ± .002 measured in sodium light
Birefringence: .056 — .060

Pleochroism: α: orange-brown α≪β=γ
β, γ: opaque

Lepidomelane is evenly dispersed through the rock. It has been separated for optical investigation and chemical analysis (table 8). The mineral is macroscopically black. Under the microscope sections subparallel with (001) have very dark green pleochroic tinges. The birefringence has been tentatively measured in two sections perpendicular to (001) using a quartz compensator. The thicknesses of the sections were established in adjacent quartz grains giving flash figures. It is very difficult to observe the complete compensation in very strongly birefringent and moreover coloured minerals; the values obtained should be regarded with some scepticism. Other minerals observed were: colourless mica, zircon, fluorite, xenotime and pyrochlore.

The sum of the weight percentages of the chemical analysis is low. In this case it cannot be modified considerably by assuming errors in the quantities of iron and alumina, as was done in the case of riebeckite, since FeO is already exceptionally high in the structural formula (see below) and partial replacement of it by Fe_2O_3 or Al_2O_3 would only lower the sum.

The structural formula was calculated according to Foster (1960). When these author's criteria for excluding certain formulas are applied, the one obtained here is correct; it is that of a lepidomelane similar to several micas quoted by her. The most significant differences are: the high Fe^{2+} (2.29; according to Foster (1960; p. 24) an octahedral occupancy of more than 2.20 positions by Fe^{2+} is not to be expected); the fact that the mineral is a Fe^{2+} dominant trioctahedral mica with nevertheless much less than .50 additional positive charges carried by trivalent and quadrivalent octahedral cations. If the analysis would be reliable, the lepidomelane is nearer to annite than the analyses quoted by Foster (1960) and Fabriès & Rocci (1965) (fig. 17). The high refractive index γ, intermediate between that of most lepidomelanes (around 1.66) and of artificial annite (1.694; Eugster & Wones, 1962) supports the obtained formula. Foster pointed to the fact that all her lepidomelanes and siderophyllites were found in pegmatites. The data on lepidomelanes from granites in Niger and Nigeria provided and quoted by Fabriès & Rocci (1965), however, prove that magnesium-poor trioctahedral micas occur in such rocks also.

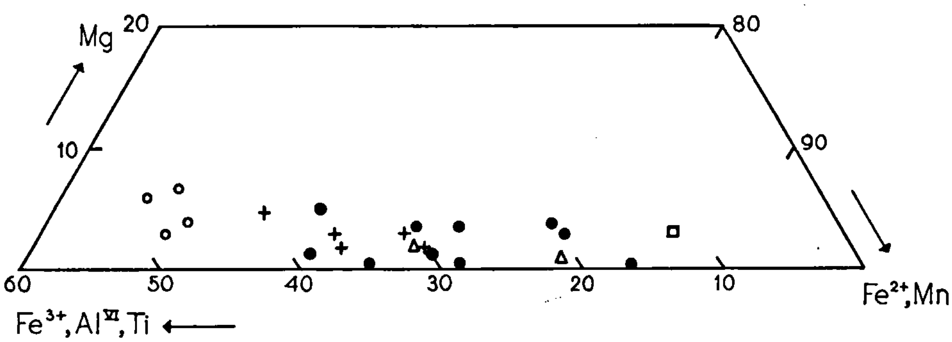


Fig. 17 Chemical compositions of lepidomelane. Solid circles: values from Foster (1960); open triangles: lepidomelane in granites, Nigeria, crosses: in perthite granite (Niger), open circles: in albite granite, Niger (Fabriès & Rocci, 1965); open square: 353 (this paper).

Magnetite-zircon gneiss

The existence of a magnetite-zircon gneiss was disclosed when describing zircon in the section mineralogy. The rock from which the sample was taken has been found in the first year of the author's investigation in the southern extremity of the gneiss band La Guia-Galiñeiro area, where it is cut off by the supposed fault. When he returned the next year to collect more of this peculiar rock, the local people told him that lightning had struck an adjacent tree and split the rock, which thereby became very suitable for building purposes. The colour of the specimen is light grey with tiny pinkish brown and black specks.

In thin section the light minerals are fine-grained compared with normal riebeckite gneisses; foliation is visualized by parallel, nearly continuous trains of quartz crystals. Magnetite and hypidiomorphic to xenomorphic zircon lie seemingly strewn out at random, embedded in the light minerals. Magnetite grains are smaller (max. 3 mm, mostly < .1 mm) but more numerous than zircons (from .6 mm downwards). A few lepidomelane flakes (enclosed within albite) and grains of pyrochlore are accessoiies.

Leucocratic gneiss

Very leucocratic gneisses almost without dark constituents were found on the southern slope of Zorro near the margin of the gneiss body (Zorro-type assemblage of light minerals), near the col between Monte Galiñeiro and hill 658m (Galiñeiro type) and at the northern extremity, N of Zamanes, of the gneiss band from the Galiñeiro to the north, where it is bent by the action of a fault.

The latter specimen (215) is the only one of all riebeckite gneisses and affiliated rocks investigated that clearly shows a tectonic influence after the growth of the albite porphyroblasts. This is evident in thin section from their undulose and fractured appearance. They have oval outlines and longest diameters (max. 2 mm) parallel to the foliation brought about by thick quartz bands. Quartz grains have all sizes from 1 mm downwards. The albite porphyroblasts are surrounded by strongly comminuted masses of microcline, quartz and albite (often as small as .1 mm). It is well visible, that the gneiss underwent strong subsequent recrystallization, for the texture of the fine-grained masses is essentially granoblastic, while the quartz of the bands is only weakly undulose and consists of more or less equidimensional grains without a marked preferred orientation. A few needles of riebeckite, a flake of lepidomelane enclosed by quartz, zircon, anatase and ore are the only other minerals present.

Aegirine-augite-bearing magnetite gneiss

An aegirine-augite-bearing magnetite gneiss (261) was found at the eastern margin of riebeckite gneiss in Vilaverde, at the foot of the ridge W of the hamlet, very near to the locality of 180, described in chapter IV. Like many other marginal gneisses it shows in thin section an assemblage of light minerals completely comparable to that of riebeckite gneiss. It is characterized by the presence of altered bright green aegirine-augite, in addition to that of magnetite (grains up to .7 mm). Other constituents are: dark brown allanite, zircon, fluorite, titanite, apatite, some flakes of orange-brown to opaque pleochroic lepidomelane and a few needles of blue-green amphibole. Several accessories could not yet be determined.

Pyroxene-bearing bluish green amphibole gneiss

Two pyroxene-bearing bluish green amphibole gneisses, collected on the W slope of the Sierra de Galiñeiro, again have a normal Galiñeiro-type aspect as far as the light constituents are concerned. The dark and accessory minerals are different, also when the two rocks under discussion are compared.

In 269 bright green aegirine-augite with the same aspect as in 261 (preceding type) is slightly more common than blue-green amphibole. Aegirine-augite is somewhat altered and has been observed surrounding and enclosed by amphibole. Parallel intergrowths were also noted. Amphibole is less altered and partly represented by radiating aggregates of thin needles. The mineral has a pleochroism: γ: bluish green; β: green; α: greyish green and $2V_\alpha$ variable between 30° and 45°. The smallest optic axial angles were measured in parts of crystals with the strongest absorption, lighter coloured parts have larger angles. The light-coloured amphibole seems younger than the darker-coloured variety since the former surrounds the latter and constitutes the radiating aggregates. Titanite grains are numerous, orange-brown to opaque lepidomelane flakes less so. Accessories are very dark brown allanite, fluorite, a few grains of zircon, apatite, epidote and opaque ore.

Aegirine-augite in the other specimen (270) was found only as small grains in albite. Bluish green amphibole has the same pleochroism as in 269, but the colour does not vary and the optic axial angle $2V_\alpha$ is 25° to 30°. The mineral has a marked extinction dispersion. Biotite has pleochroism from yellowish brown to dark brown and is somewhat altered, like amphibole into limonite. Titanite, fluorite, apatite and a few zircons are accessories.

Bluish green amphibole-bearing lepidomelane gneiss

On the dump of rocks excavated from the new railway tunnel near La Guia dark-coloured gneiss (700) has been found, in addition to riebeckite gneiss and paragneiss. In thin section it showed to be a bluish green amphibole-bearing lepidomelane gneiss. Lepidomelane has a pleochroism from yellow-brown to very dark greenish brown. The amphibole, partly altered into green biotite and limonite, has about the same pleochroic scheme as that in 269 and 270 (preceding type) but stronger absorption and a very small optic axial angle. It therefore closely resembles the amphibole in some amphibole-biotite rocks and gneisses described in the next chapter as a ferrohastingsitic variety. The light minerals offer no new aspects. Zircon is rather abundant, in hypidiomorphic crystals up to .5 mm. Other accessories are: fluorite, dark brown allanite, probably intergrown with very fine-grained xenotime in the same way as in radioactive gneiss, apatite, pyrochlore and siderite. The latter mineral has the same habit as in the riebeckite gneisses of La Guia (cp.: section mineralogy). Pyrochlore has been observed enclosed within zircon.

On the premises of the Spanish naval school "E.T.E.A.", situated on the northeastern side of La Guia peninsula, a contact between paragneiss and "riebeckite gneiss" was found behind the building "Tesla". In the outcrop, which is only about 10 m wide, genuine riebeckite

gneiss is not present, several kinds of marginal rocks being found instead. The collected specimens will be separately described going from paragneiss down into marginal gneiss.
On the paragneiss side of the contact fresh rocks are scarce. In the vicinity of the contact, which could not be located very precisely, because of only small differences in colour and texture between the two rocks, a fine-grained biotite paragneiss has been collected (786). Quartz is the largest mineral in the thin section with undulose elongated grains up to 1 mm in discontinuous bands parallel to the schistosity which is further marked by small parallel flakes of biotite. The latter mineral has red-brown colours of β and γ. Larger flakes (max. .4 mm) are less oriented than the small ones. Both minerals lie embedded in a mass of feldspar crystals of max. .5 mm diameter. At first sight the feldspars seem to be plagioclase metablasts as described in chapter VII. Closer inspection reveals, however, that most plagioclase has been replaced by microcline, only a few oligoclase metablasts, with enclosed quartz droplets, having been left. The remnant plagioclase is sericitized. Apatite, zircon and ore are accessories.
Of 787, found 50 cm lower, it cannot be made out with certainty whether it should be classified as a paragneiss or as a marginal type of riebeckite gneiss. It is more leucocratic but, with the exception of a few large plagioclases and microclines (up to 2.3 and 3 mm respectively), it is fine-grained (< .3 mm). Quartz crystals are about equigranular. Plagioclase (oligoclase) is twinned on (010) and (001), sericitized and replaced by microcline. A few larger metablasts contain quartz droplets and crystals. Microcline is slightly perthitic. Biotite has (reddish) brown and green colours of β and γ and is partly chloritized. Foliation is caused by the arrangement of biotite in bands (the individual flakes are more or less parallel in the same direction) and by the elongated shapes of the larger plagioclases and microclines. Zircons are small and hypidiomorphic to xenomorphic. Apatite, ore and altered fine-grained assemblages resembling the allanite-xenotime intergrowths observed in radioactive gneisses and in the block on the dump S of La Guia (bluish green amphibole-bearing lepidomelane gneiss) were noted as accessories.
The next specimen (788) was taken 50 cm below 787. Like the latter sample it has the macroscopical aspect of a marginal biotite gneiss but in thin section this rock is also fine-grained, with quartz, oligoclase and microcline, often replacive towards oligoclase. Porphyroblasts of albite up to 2 mm seem to be younger than microcline. A few of them enclose tiny crystals of a green amphibole. Biotite is brown or green and altered into chlorite. It is arranged in irregular strings causing the foliation of the gneiss. Individual flakes show no marked preferred orientation. Zircon is rather common but the crystals are small (< .2 mm) and hypidiomorphic or xenomorphic. Prism faces are often visible. Apatite, titanite, fluorite and altered allanite occur in accessory amounts.
789 was found 3 m below the foregoing sample and is part of a fresh, dark grey block surrounded by weathered gneiss. It is the first sample with a true alkaline gneiss texture (Galiñeiro-type) in thin section. Biotite (mostly brown; green biotite and chlorite in small amounts) is the only important dark constituent. Albite encloses a.o. small crystals of dark green amphibole with a small optic axial angle. Titanite, apatite, fluorite, altered allanite and opaque ore were observed in small quantities. Zircon has not been recognized.
790, collected 1.5 m more downwards in the section closely resembles 789 and contains major crystals of green amphibole in addition. This mineral has pleochroism from blue-green (γ) to green (β) and brownish yellow (α), strong absorption and $2V_\alpha$: 40°–45°. Alteration into vesicular brown biotite has proceeded rather far. Vesicular biotite occurs also in 789 and the possibility should not be excluded, that that rock originally contained green amphibole outside the albite porphyroblasts as well. Bipyramidal zircons of moderate dimensions are present in small quantity in the slide of 790.
1 m lower, samples were taken from a leucocratic gneiss (792). It has again the light mineral assemblage of a Galiñeiro-type riebeckite gneiss. Flakes of biotite (brown or green and altered into chlorite) have maximum lengths of .25 mm. Amphibole is absent but for a few needles within albite. The accessories are the same as in 790.

Though the two contact series described here and in the section biotite gneiss give an impression of the changes that take place in alkaline gneisses in the immediate vicinity of the contact, continuous sections from paragneiss to riebeckite gneiss proper are nowhere exposed. The railway tunnel through the La Guia peninsula crosses the contact but was already cemented when the author started mapping that area. The tunnel has not been geologically sampled by the constructing firm and the foremen could not give more information than that a bad zone with strongly weathered rock and much water had been struck in the middle of the tunnel.

Xenolithic inclusions

Fine-grained biotite-rich rocks, believed to be xenolithic inclusions, were found at a few places only: in the path on the marginal biotite gneiss, between Presa and the forest road to the south, not far from that road (530); along the path from Herbille to Abelenda in the lowest part of the eastern riebeckite gneiss band (453) and on the seashore of La Guia just north of the "Vulcano" ship-yard (718), fig. 18.

The first and second outcrop have such dimensions, that the shapes of the xenoliths could not be established. The specimens are very similar, dark grey coloured with very thin, white microfolded bands (< 1 mm). A few lenses of quartz are thicker (up to 1 cm) and always surrounded by narrow white rims.

Under the microscope it appears that quartz is nearly exclusively present in the lenses. It is coarse-grained (max. 2.5 mm), undulose and has intended boundaries. The rims around quartz and the white bands consist of fine-grained microcline (< .3 mm) with only a little albite. The crystals of the rims have elongated shapes perpendicular to the boundary of the quartz and subparallel crystallographical orientations in groups. The same is the case in the bands, but the grains are equidimensional there.

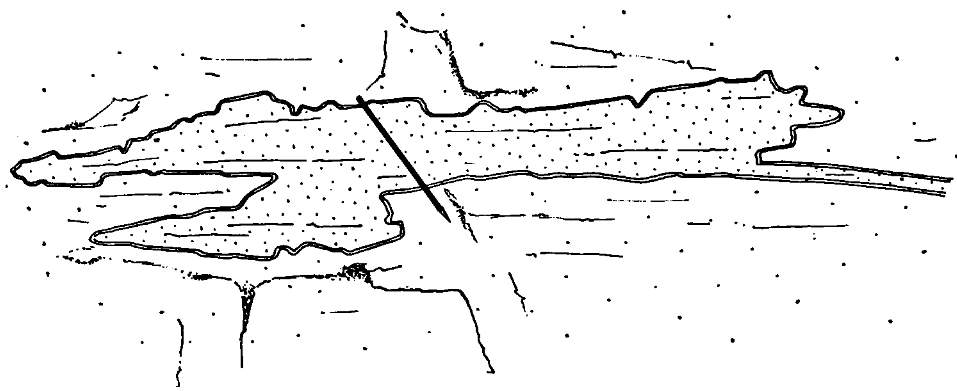


Fig. 18 Mica-rich xenolith in riebeckite gneiss, shore of La Guia.

The macroscopically grey parts of 530 consist of microcline, some albite and biotite. All minerals are generally smaller than .3 mm; a few slightly perthitic microclines up to .85 mm were noted. Biotite has orange-brown colours of β and γ; part of its flakes is preferentially oriented with (001) about parallel to the axial plane of the microfolding. Accessories are apatite, small zircons and altered allanite.

The grey parts of 453 are less homogeneous. Albite is a more important constituent than in 530. It is partly present as porphyroblasts up to 2.5 mm across enclosing rutile, titanite, opaque ore and only little biotite; it seems to have grown at the expense of microcline. The feldspar or the fine-grained aggregates constituting the remainder of the grey parts is difficult to determine because of the presence of many small flakes of muscovite. It is thought that albite predominates. The grain size is even finer than in 530: mostly smaller than .2 mm. Biotite is orange-brown and smaller than .3 mm in the parts without albite porphyroblasts. These flakes show a weak preferred orientation. In the neighbourhood of albite porphyroblasts larger biotites, up to 1 mm long and thick, have seemingly grown at random.

The third inclusion is less than a metre long and clearly folded (fig. 18). It is surrounded by a 1.5 mm thick rim of very light colour as compared with that of the inclusion or of the enveloping gneiss.

The latter is a microcline-rich biotite gneiss (possibly riebeckite gneiss altered by the influence of intrusive two-mica granite (cf. next section) with large microcline enclosing smaller crystals of the same mineral, brown biotite, zircon (up to .2 mm) and ore. Albite porphyroblasts were not observed.

The transitional zone consists of a mosaic of microcline with only little albite and a few ore grains.

Against this zone, the biotite of the xenolith is somewhat limonitized and with very dark red brown colours of β and γ, changing inwards gradually into a lighter tinge, until, about .6 mm from the contact, the colour has a reddish brown tinge normal for the rest of the xenolith. The first centimetre from the contact consists of albite, microcline, biotite and some muscovite. The latter minerals have grown in a peculiar way: many flakes, each not longer than .3 mm, lie parallel to form groups up to, e.g., 3 mm long and 1 mm thick or, in another case, 1 mm long and 2 mm thick. The aggregates themselves have random orientations. Aggregates, crossing each other were also observed. The frequency of biotite and muscovite is such that it is difficult to determine each grain of the embedding feldspar. It is fairly certain, however, that albite predominates over microcline. The crystals of both minerals range up to about 1 mm. Small patches with subparallel-oriented feldspar grains are not uncommon. A few small grains of a colourless mineral, initially thought to be corundum, occur in this part. It has a very high refringence, weak to moderate birefringence and variable elongation. The optic axial angle, however, is positive and at least 50°.

The second, more interior, part of the xenolith has a distinct aspect: muscovite and the unidentified mineral are absent, biotites are arranged individually and at random, microcline is much commoner than albite, the dimensions of all minerals are generally smaller than .3 mm and rutile, (anatase?), some altered allanite and clusters of ore were recorded in this part. Feldspar mosaic areas of up to 2 cm^2 display subparallel extinctions. Rather large equidimensional apatites (max. .5 mm) and small mostly rounded zircons were found in both parts.

Contacts with two-mica granite

As stated in the introduction of this chapter riebeckite gneisses were intruded by younger granitic rocks at two places only: the shore of La Guia and the eastern slopes of Cepudo and San Bartolomé, in both cases by two-mica granite. Since each locality has its own characteristics, it will be necessary to describe the contacts separately.

Shore of La Guia

The contact first appears W of an old quay due north of the summit. From there it continues in westerly direction, mostly between the high and low water marks. NW of the summit it rises upwards and is covered by eucalypt forest, until SW of the summit, riebeckite gneiss is found again at sea level. The best exposed parts of the contact lie in a military zone, which comprises the NW edge of the peninsula and can only be visited with a special permission. The contact is sharp and straight. The granite is medium- to coarse-grained equigranular two-mica granite. In the last 20 cm from the contact muscovite is absent. Quite regularly a 3–5 cm thick biotite-bearing pegmatite was noticed between granite and gneiss. The riebeckite gneiss has been altered to biotite gneiss in the neighbourhood of the contact. Adjacent to the latter, biotite-rich schlieren were noted locally in the granite.

At Punta de Areiño a series of 5 specimens has been collected: granite somewhat more than a metre, 30 cm and less than 20 cm from the contact and gneiss 40 cm and 5–6 m from the place where the contact is situated at the surface. It was impossible to find fresh gneiss at intermediate distances.

The three granites display characteristics as given in the preceding chapter. Thin sections demonstrate that the first specimen (799) contains more muscovite than biotite and some tourmaline, the second (795) some microclines with micrographic quartz intergrowths. The third (798) is muscovite-free and more inequigranular than the former (crystals up to 7 mm but also some masses of crystals not exceeding .25 mm). Micrographic intergrowths of microcline and quartz are common.

The biotite in the gneiss nearest to the contact (796) has a pleochroism from dark greenish

brown, occasionally dark green (γ and β) to yellow-brown (α). Foliation has disappeared. The light constituents form an inequigranular granoblastic aggregate of quartz, microcline and albite. Large albite porphyroblasts, characteristic of the unaffected riebeckite gneisses, are absent. Albite is not much larger than the other minerals (max. 1.8 mm) and twinned after the albite law. Replacement relations with microcline are common (in contrast with the normal gneisses, where this is an unusual feature). As in granite some albite is older than microcline and has been partly replaced by it, while other albite is younger and replaces microcline. A few albite and quartz crystals enclose tiny grains of probably dark green amphibole. Hypidiomorphic zircons up to .5 mm, fluorite, some apatites and altered allanite(?) are accessory minerals.
The last specimen (797) is much finer-grained than 796. Quartz crystals are the largest grains in the section, measuring up to 1 mm. They lie isolated or grouped together in a granoblastic aggregate of quartz, albite (both < .2 mm) and microcline (max. .8 mm). The grains of these aggregates have subparallel extinctions over areas of 1–4 mm^2. The larger microclines often surround the other minerals and seem to be younger. Bluish green riebeckite is the predominant dark constituent. It has been partly replaced by siderite and – to a less extent – by a green micaceous mineral. A few flakes of very dark brown lepidomelane (α: orange-brown) are also partly replaced by siderite. Zircons have overgrowths of siderite and are xenomorphic to hypidiomorphic with a max. diameter of .5 mm. Rather much fluorite and ore and some crystals of relatively strongly birefringent apatite are the accessories.
The thin section (576), collected at the same locality as the preceding samples, contains the very contact. There is a strong difference in grain size. Foliation is present in the gneiss, the biotites have weakly distinct colours and apatite is common in granite, whereas large zircons abound in the gneiss. Albite porphyroblasts are absent in the gneiss, replacive relations between albite and microcline were often noted.

A xenolith of presumably riebeckite gneiss, now muscovite-bearing biotite gneiss, was found in two-mica granite along the shore, some 350 m SW of Punta de Areiño. In outcrop the gneissic foliation is well-preserved; in thin section only the presence of large zircons and xenotime suggests that the rock originally was a gneiss related to those described in this chapter. The other constituents are strongly recrystallized. The – generally albitic – plagioclase has been partly replaced by microcline. It is twinned after the albite law. Biotite is represented by reddish brown poeciloblasts of max. 2 mm, intergrown with or enclosing some muscovite. A few muscovites with the lepidoblastic habit often observed in granites and paragneisses were noted as well.

Slopes of Cepudo and San Bartolomé

A narrow band of rocks macroscopically closely resembling riebeckite gneiss, altered and intruded by coarse-grained inequigranular two-mica granite, is exposed on the eastern slope of Cepudo, the eastern and northern slope of San Bartolomé and NW of the latter locality. It is less than 100 m wide and ends at both extremes by total assimilation by the granite. Outcrops lie exclusively in paths and along a forest road. Further south, rock with a similar gneissic aspect separates coarse-grained from medium-grained inequigranular two-mica granite along the road Vincios-Nigrán. Fresh outcrops are scarce. The contact itself is rarely visible; in most cases a zone with gneissic ghost structures in a mass of more homogeneous fine-grained biotite granite occurs in between.

In thin section it appears that riebeckite has only rarely been preserved. The fact that it is present in some samples, while most others display other characteristics familiar with riebeckite gneiss (a.o.: presence of bipyramidal zircons, absence of apatite) and that these rocks lie within a restricted zone parallel with their dip and strike, cause the author to consider the whole band as partially modified riebeckite gneiss.

Three gneisses most resembling riebeckite gneiss are fine-grained. Porphyroblastic albite, as found in Galiñeiro-type gneisses, has never been observed. Replacement of albite by microcline or the reverse is often of frequent occurrence. The twinning of albite is always finely lamellar on (010). Microcline is present in two generations: small crystals with sharp twinning and larger ones, often enclosing the former with less well-defined cross-hatching. Some albite is clearly younger than the large microcline, replacing the mineral in patches of small nearly parallel-oriented crystals. The same relations were noticed in thin sections of contact rocks at La Guia. One lepidomelane-riebeckite gneiss (514) is microfolded (cp. fig. 12b). In thin section the only evidence of this microfolding is the sinuous arrangement of quartz bands and strings of dark minerals. A lepidomelane-magnetite gneiss was also found. It contains an accessory amount of blue amphibole. Large microcline in these rocks ranges up to 2.5 mm in diameter. Albite, small microcline and a considerable part of the quartz have sizes below .7 mm. Lepidomelane has nearly opaque (very dark brown or green) colours of β and γ and orange-brown or light brown ones of α. The mineral is often limonitized.

Biotite gneisses not in directly visible contact with granitic rock are coarser in grain and consequently show less difference between the sizes of large microclines and albite. Grains of 1 mm are not rare. They generally enclose crystals of quartz. The arrangement of biotite is the only indicator of the former existence of a gneissic fabric. Microcline-albite replacements are still common. Biotites have pleochroism with dark reddish brown tinges of β and γ. A few crystals of apatite were noted in only one of three thin sections.

A sharp, discordant, contact between biotite gneiss and biotite granite is present in 524. The gneissic part has a weak foliation brought about by biotite, is fine-grained (like the "gneisses most resembling riebeckite gneiss" mentioned above) and microcline-rich, but shows very little replacement relations between microcline and albite. The granitic counterpart is coarser in grain with crystals generally exceeding 2 mm, non-foliated and rich in apatite, while large zircons as seen in the gneissic part are lacking. Microcline often encloses small hypidiomorphic plagioclases in random orientations. Replacive relations with albite were recorded. Biotite is less common than in gneiss.

Four specimens were investigated exhibiting several stages of assimilation by or mobilization into biotite granite. In thin sections it is hardly possible to define gneissic and granitic parts. Large zircons and apatites are no longer useful criteria. In one case the grainsize still showed some difference; small hypidiomorphic plagioclases enclosed within microcline are rare in recognizable gneissic relics. Everywhere plagioclase has an albitic composition. Replacive relations between microcline and albite are nearly absent. Biotite has red-brown colours of β and γ. The zircon in 529 has idiomorphic habits with an important participation of the prism face. Parts of this sample consist of quartz and albite; microcline is found locally concentrated into large crystals commonly exceeding 1 cm.

The gneissic rock constituting the septum between the two granites along the road Vincios-Nigrán (632) is composed of quartz, microcline, oligoclase, biotite, a little muscovite and accessory amounts of zircon and monazite. The feldspars show replacive relations and generally measure about 1 mm across. They enclose quartz crystals. Zircon has strongly prismatic tendencies. Only its gneissic appearance, the absence of apatite and its position in the continuation of the "riebeckite gneiss" band further north, led the author to the assumption that this rock might belong to the same suite.

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Rock analyses

Chemical analyses are available of three specimens of riebeckite gneiss. All belong to the Galiñeiro-type. 61 Cor. 20 is an astrophyllite- and lepidomelane-bearing riebeckite gneiss, 67 an aegirine-riebeckite gneiss and 233 an astrophyllite-bearing aegirine-riebeckite gneiss (table 9). Since it is very difficult to provide for comparison a sensible selection from the multitude of analyses of per-alkaline granitic rocks quoted in the literature, the author only gives the three analyses of acid alkaline gneisses known to him: one of aegirine-riebeckite gneiss from Carn Chuinneag, Scotland and two of aegirine-riebeckite gneiss from near Gloggnitz, Austria (the alkaline gneisses of Alto Alentejo, Portugal, of which many analyses were made, are much poorer in quartz).

As expected the norms show that all rocks are considerably undersaturated in

TABLE 9 *Chemical analyses of per-alkaline gneisses*

	1	2	3	4	5	6
SiO_2	75.52	71.03	73.20	73.80	76.03	76.60
Al_2O_3	10.24	11.83	11.41	11.90	11.74	10.75
Fe_2O_3	1.44	3.56	4.91	1.90	2.44	2.42
FeO	3.20	1.49	1.45	1.91	.65	1.10
MnO	.07	.05	.04	.12	.04	.03
MgO	.13	1.19	.25	.33	.04	.08
CaO	.45	.83	.23	.30	.11	.19
Na_2O	3.95	4.55	4.60	5.05	4.74	4.68
K_2O	4.30	4.40	3.99	4.93	4.07	4.06
$H_2O\pm$	.38	.69	.28	.13 .04	.04 .28	.06 .27
TiO_2	.28	.37	.27	.23	.10	.09
P_2O_5	.01	.05	.07	—	—	—
Li_2O	.24	.26	.30	—	—	—
ZrO_2	—	—	—	.04	—	—
Total	100.23	100.30	101.00	100.68	100.28	100.33
			Norms			
Q	32.0	23.7	29.2	24.2	31.3	33.0
Or	26.0	26.5	23.5	29.0	24.0	24.5
Ab	31.0	39.0	40.0	36.0	41.0	35.0
Ac	4.0	2.0	2.0	5.2	1.6	6.0
Ns	.2			1.2		
Wo	1.0				.2	.4
Di		3.2	.8	1.2		
En	.6	2.0	.2			
Hy	4.8			3.4		
Mt		2.7	2.7		1.2	.3
Hm		.3	1.2		.5	.6
Il	.4	.6	.4	.4	.2	.2

1. Astrophyllite- and lepidomelane-bearing riebeckite gneiss, 61 Cor. 20; S of La Guia, Vigo, Spain. Analyst: Mrs. H. M. I. Bult-Bik.
   Separately determined: .19 % ZrO_2, .037 % Nb_2O_5, .02 % Ta_2O_5, by Analytical Laboratory, N.V. Hollandse Metallurgische Industrie Billiton, Arnhem, and weighed with Al_2O_3 in the rock analysis.
   Rb: 259 p.p.m., Sr: 11 p.p.m., by Laboratory for Isotope Geology, Amsterdam.
   The Li_2O content has been disregarded when calculating the norm.
2. Astrophyllite-bearing aegirine-riebeckite gneiss, 233; E of chapel Virgen de las Nieves, Galiñeiro Range, Vigo, Spain. Analyst: Mrs. H. M. I. Bult-Bik.
   The Li_2O content has been disregarded when calculating the norm.
3. Aegirine-riebeckite gneiss, 67; Hill 658 m, Galiñeiro Range, Vigo, Spain. Analyst: Mrs. H. M. I. Bult-Bik.
   The Li_2O content has been disregarded when calculating the norm.
4. Gneissic aegirine-riebeckite granite, Carn Chuinneag, Scotland (Peach et al., 1912).
   Spectrographic analysis of riebeckite gneiss from summit of Carn Chuinneag by Dr. S. R. Nockolds gave a.o. Li: 65 p.p.m., Zr: 1000 p.p.m., Sr: $<$ 3 p.p.m., Rb: 125 p.p.m. (Harker, 1962).
5. Strongly mylonitized aegirine-riebeckite gneiss, block on SW slope Haidenkogel, Gloggnitz, Austria (Zemann, 1951).
6. Relatively little gneissic aegirine-bearing riebeckite gneiss, Orthof, Gloggnitz, Austria (Zemann, 1951).

TABLE 10 *Lithium in per-alkaline rocks, alkali amphiboles and pyroxenes*

Rock name (when stated) and locality	Weight percentages Li_2O		Reference
	Total rock	Mineral	
Aegirine, Dzhuro-sai, Kirgiz S.S.R.		.08	Petrova and Skorobogatova, 1963
Aegirine, veinlets in riebeckite-bearing rocks listed below		.11	
Riebeckite in albite-malacon-riebeckite vein, Siberia		.74	
		.40	
		.79	
		.93	
Riebeckite in riebeckite-microcline-albite rock, Siberia		.80	
		.69	
		1.17	
		.43	
		.36	
Riebeckite in albitite, Siberia		1.09	
		.79	
		.16	(error?; in text Li_2O in this group is stated to vary from .50 to 1.09 %)
		.50	
Riebeckite in granite, Siberia		.72	
Riebeckite, Colorado, U.S.A.		.70	
Riebeckite, Dobruja, Rumania		.315	
Riebeckite in pegmatite, Siberia		.58	
Arfvedsonite, Urmavaraka, Kola peninsula, U.S.S.R.		.105	
		.15	
Arfvedsonite, Mariupol, Ukraine, U.S.S.R.		.15	
Riebeckite in aegirine- riebeckite granite, Kigom Hills, Nigeria		.56	Greenwood, 1951
Riebeckite in albite-riebeckite granite, Kaffo valley, Liruei complex, Nigeria		2.20	Borley, 1963
Riebeckite in albite-riebeckite granite, Amo complex, Nigeria		1.76	(spectrographic determinations
Riebeckite in albite-riebeckite granite, Kigom Hills, Nigeria		1.16	of Li_2O in the
Riebeckite in 11 other Nigerian granites		.42—.99	same specimens yielded lower values than the quoted ones that were determined photometrically: 2.16, 1.3, 1.3, .32—.97)
Aegirine-riebeckite microgranite, Kûngnât, S Greenland	.19		Upton, 1960
Soda-hornblende granite, Kûngnât	.013		
Riebeckite-astrophyllite granite, Kûngnât	.016		
Aegirine-arfvedsonite granite (Ilímaussaq granite), S Greenland. Variation of Li_2O in 11 analyses	.005—.019		Hamilton, 1964
Riebeckite-aegirine gneiss, Carn Chuinneag, Scotland. Rock and riebeckite	.014	.027	Harker, 1962
Astrophyllite-lepidomelane-riebeckite gneiss, 61 Cor. 20, La Guia, Vigo, Spain. Rock and riebeckite	.24	.58	This paper
Riebeckite-aegirine gneiss, N of hill 658 m, Galiñeiro range, Vigo, Spain. Rock and riebeckite 583	.21	1.01	
584	.26	.90	
Astrophyllite-bearing aegirine-riebeckite gneiss, 233, E of Virgen de las Nieves, Galiñeiro Range, Vigo, Spain	.26		
Aegirine-riebeckite gneiss, 67, Galiñeiro range, Vigo, Spain	.30		

TABLE 11 *Zirconium in per-alkaline granitic rocks*

ZrO_2 weight %	Rock name and locality	Reference
2.32	Aegirine-riebeckite granite dyke, Ampasibitika, Malagasy Republic	Lacroix, 1923 a
.69		
.59		
.10	Arfvedsonite granite, Koedoeslaagte-Schurvedraai, Transvaal-Orange Freestate, S Africa	Hall & Molengraaff, 1925
.05	Soda granite, Rietfontein, Transvaal-Orange Freestate, S Africa	
.51	Riebeckite-aegirine granite, Noqui, Angola	Holmes, 1915
.29	Aegirine-riebeckite granite, Cambulo, Lunda, Angola	Montenegro de Andrade, 1950
.11	Aegirine-riebeckite-lepidomelane granite, Quinga (Noqui), Angola	Montenegro de Andrade, 1959
.25	Aegirine-riebeckite-lepidomelane granite, Pic Cambier, Bas-Congo, Congo Republic	Mortelmans, 1948
.25	Albite-riebeckite granite, Kaffo Valley, Liruei Hills, Nigeria	Beer, 1952
.37	Albite-riebeckite granite, Kaffo Valley, Liruei Hills, Nigeria	Jacobson, MacLeod & Black, 1958
.18	Riebeckite-aegirine granite, Liruei Hills, Nigeria	
.10	Aegirine-riebeckite granite, Kudaru Hills, Nigeria	
.08	Riebeckite-astrophyllite-biotite granite, Teria, Amo, Nigeria	Butler & Smith, 1962
.18	Aegirine-riebeckite granite, Bouir el Halou, Mauretania	Jérémine, 1942
1.17	Rockallite, Rockall, Atlantic Ocean	Washington, 1914
.66	Rockallite, Rockall, Atlantic Ocean	Lacroix, 1923 b
.82	Aegirine granite, Rockall, Atlantic Ocean	
.56		
.86		
.46		
.38	Aegirine granite, Atlantic Ocean, 12 miles N of Rockall	
.34	Aegirine granite, Rockall, Atlantic Ocean	Sabine, 1960
.25	Astrophyllite ekerite, Bö-kapelle, Luksefjell, Norway	Brögger, 1932
.18	Epidite ekerite, Jaeringen, Nordmarka, Norway	
.29	Soda-amphibole granite, Kûngnât, S Greenland	Upton, 1960
.97	Aegirine-riebeckite microgranite, Kûngnât, S Greenland	
.22	Riebeckite-astrophyllite granite, Kûngnât, S Greenland	
.27—$\gg$1	Variation in 11 aegirine-arfvedsonite (Ilímaussaq) granites, S Greenland	Hamilton, 1964
.08	Riebeckite-astrophyllite granite, Mt Tremont, New Hampshire, U.S.A.	Butler & Smith, 1962
.04	Aegirine-riebeckite gneiss, Carn Chuinneag, Scotland	Peach & others, 1912
.14	Aegirine-riebeckite gneiss, Carn Chuinneag, Scotland	Harker, 1962
.19	Astrophyllite-lepidomelane-riebeckite gneiss, La Guia, Vigo, Spain	This paper

alumina, which caused the appearance of alkali amphiboles and pyroxenes. The three analyses from the author's area show considerable differences among themselves; they reflect the wide compositional variations mentioned also in the section petrography.

Partial analyses

Lithium

Data on the Li contents of per-alkaline granitic rocks and of the riebeckite and aegirine they contain are scarce in the literature. More is known about the minerals and rocks separately (table 10). Petrova and Skorobogatova (1963) analyzed by flame photometry 24 samples of alkali amphiboles and pyroxenes from other occurrences than the one specifically described by them (but not better localized than: in Siberia), both·in- and outside the U.S.S.R. Lithium oxyde was found in only eight of the samples, seven of which are listed in their paper and quoted in table 10. The highest content was measured in riebeckites, much less in arfvedsonite. Only one sample of aegirine contained Li_2O.

The lithium content of riebeckite 61 Cor. 20 aroused the author's interest in the distribution of this element in the gneisses studied by him. Partial analyses were made of two riebeckite-bearing aegirine gneisses (583 and 584) in which Li_2O can

TABLE 12 *Zirconium in riebeckite and aegirine*

ZrO_2 weight %	Source rock and locality	Reference
.75	Riebeckite in quartz vein, El Paso Co, Colorado, U.S.A.	König, 1877
.04	Riebeckite in granite, Evisa, Corsica	Orcel, 1920
.31	Riebeckite in granite, N of Kudaru, Nigeria	Bain, 1934
.03	Riebeckite in gneiss, Carn Chuinneag, Scotland	Harker, 1962
.03	Riebeckite in gneiss, 61 Cor. 20, La Guia, Vigo, Spain	This paper
.07	Riebeckite in gneiss, 583, N of hill 658 m, Galiñeiro Range, Vigo, Spain	
.89	Aegirine, in trachyte, Jellore, E Australia	Jensen, 1908
.41	Acmite, Quincy, Massachusetts, U.S.A.	Washington & Merwin, 1927
.20	Acmite, Rundemyr, Norway	
1.34	Acmite, Brevik area, Norway	
.15	Acmite, Kangerdluarssuk, S Greenland	
1.84	Aegirine, in pegmatite, Alter Pedroso, Portugal	Burri, 1928
.20	Aegirine, Eikarholmen, Norway	Degenhardt, 1957
.50	Aegirine, Barkevikscheeren, Brevik, Norway	
.77	Aegirine, Caldas de Monchique, Portugal	
< .1	Aegirine, in aegirine-acmite granite, Rockall Island	Sabine, 1960
.135	Aegirine in gneiss, 583, N of hill 658 m, Galiñeiro Range, Vigo, Spain	This paper

hardly be accommodated in another mineral than riebeckite; of the latter partial analyses were also made (table 10). The author's values appear to be the highest as far as the total rocks are concerned and among the highest when the percentages for riebeckite are compared.
The results of the Li_2O analyses of the five gneisses from the investigated areas indicate also that the Li_2O content of these rocks is remarkably constant, whereas that of the riebeckites fluctuates strongly.

Zirconium, Rubidium, Strontium, Niobium

The zirconium content of 61 Cor. 20 is of the same order as that of riebeckite gneiss from the summit of Carn Chuinneag but rather low when compared with that of other per-alkaline granitic rocks (table 11).
The Rb, Sr and Nb contents of several per-alkaline granites and gneisses are compiled in table 13. It appears that Rb is more common in astrophyllite- and biotite-bearing riebeckite granite and gneiss than in rocks devoid of these minerals. The low value of Sr and relatively high one of Nb agree well with the statement of Butler and Smith (1962; p. 951) that riebeckite is present when Sr is below about 50 p.p.m. and Nb is above the limit of detection.

TABLE 13 *Rb, Sr and Nb in per-alkaline granitic rocks*

p.p.m.			Rock name and locality	Reference
Rb	Sr	Nb		
160	(< 40)	80	Aegirine-riebeckite granite, Liruei, N Nigeria.	Butler&Smith, 1962.
230	(< 40)	70	Riebeckite-biotite granite, SW of Teria station, Amo, N Nigeria.	
380	(< 40)	110	Riebeckite-astrophyllite-biotite granite, Teria, Amo, N Nigeria.	
350	(< 40)	150	Riebeckite-astrophyllite granite, Mt Tremont, New Hampshire, U.S.A.	
270	38	275	Riebeckite-astrophyllite granite, Kûngnât, S Greenland.	Upton, 1960
125	tr (< 3)		Riebeckite gneiss, summit Carn Chuinneag, Scotland.	Harker, 1962
258	11	260	Astrophyllite- and lepidomelane-bearing riebeckite gneiss, 61 Cor. 20, S of La La Guia, Vigo, Spain.	This paper; Priem et al., 1966

IV. THE AMPHIBOLE-BIOTITE ROCKS AND ASSOCIATED GNEISSES

FIELDS ASPECTS

Mineralogically all samples belonging to the group to be described in this chapter are roughly similar, but in detail and also when textures and respective quantities are concerned the complex appears to consist of a great variety of types, many of them macroscopically indistinguishable. To avoid difficulties with nomenclature during the fieldwork, the whole group has been dubbed "Zamanite complex" [1]). For briefness' sake this name will also be used in this chapter.
A detailed map of the area under discussion with the localities of the investigated samples and chemical analyses are given on plate 2.

Large outcrops are absent. Flat slabs of rock, probably caused by exfoliation, are of frequent occurrence in paths and vegetation. In other places the rock is thoroughly decomposed and yields fertile soil, e.g. around Zamanes.

Because of the inconspicuous foliation, measurements of dip and strike were difficult to make. In the rock slabs the foliation in some cases proved to have a direction oblique to the surfaces of the slabs. Where measured, the dip is smaller than 45°, the strike is rather variable, especially in the areas with subhorizontal foliations. Microfolds were never observed.

Leucocratic planar gneisses with a texture comparable to that of the riebeckite gneiss constitute a type apart in the NE of the complex and in one isolated outcrop in the south of it. Some carry green amphibole and biotite, in others amphibole is lacking. Small quarries were opened in this gneiss. Like the riebeckite gneiss the rock decomposes into barren sandy soil with a vegetational cover of pine, heather and gorse. The strike of the foliation is about N-S, the dips (to the west) rarely exceed 40°. Microfolds have not been observed in these rocks either.

Amphibolites with the characteristics described in the next chapter do not occur within the Zamanite complex. In a few places dark fine-grained dyke-like rocks were found *in situ* and as float. Their mineralogical compositions, however, are totally different from those of the amphibolites.

Pegmatites are rather common. They are poor in dark minerals; most of them have sharp parallel contacts and thicknesses rarely exceeding a few decimetres.

The Zamanite complex was subdivided using both macroscopical and microscopical criteria. Several rock types show gradual transitions into others. In the following pages all types will be described. At the end a review will be given of the complex relations between the several types as observed in outcrop, specimen and thin section. A discussion of the data presented in this chapter follows in chapter IX.

PETROGRAPHY

Dark-coloured biotite-amphibole rocks with basic plagioclase

Fresh specimens have a dark greenish-grey colour. In most of them hornblende, biotite and plagioclase are visible with the unaided eye. The hornblende and plagioclase have sizes around four to five millimetres in several samples. Saussuritized plagioclase is cream-coloured in the hand specimen. A weak foliation is brought out by the parallel arrangement of elongate aggregates of dark minerals in some of the specimens collected.

[1]) After Zamanes, a hamlet situated in the northern part of the complex, where the author stayed during his fieldwork.

A description will be given of two chemically analyzed rocks and of interesting phenomena observed in the other eleven thin sections.

866 derives from the northernmost occurrence of rocks of this type. Plagioclase, green hornblende and biotite are the main constituents of the rock. Since the amount of plagioclase is somewhat larger than that of the dark minerals, the rock is not really melanocratic in spite of its macroscopically dark appearance. Green hornblende (γ: blue-green; β: green; α: yellowish brown; $2V_{\alpha}$ large) and brown biotite occur intermingled in elongate aggregates with an inconspicuously parallel arrangement. The grains themselves, however, do not exhibit a preferred orientation. The maximum lengths of hornblende and biotite are .7 and .5 mm respectively. At two localities in the thin section some colourless clinopyroxene (probably diopside) has been observed in irregular implication intergrowth with green hornblende and unaltered plagioclase. Tiny drops of titanite ($<$ .02 mm) are common in hornblende, biotite

Fig. 19 Diopsidic pyroxene vermicules (barbed contours) in limpid plagioclase around altered basic plagioclase. Biotite (closely spaced lines), green amphibole (widely spaced lines) and titanite (dark) surround the plagioclase aggregate. Dark-coloured biotite-amphibole rock with basic plagioclase (866).

and clinopyroxene; their distribution is irregular, some parts of e.g. hornblende being crowded with, others completely devoid of them. Dense clusters of titanite with diameters between .5 and .7 mm and consisting of grains up to .15 mm but mostly much smaller, often grouped around a core of opaque mineral (probably ilmenite), are very common within the aggregates of dark minerals.

Plagioclase lies between these aggregates. When surveyed with low magnification the crystals show more or less uniform extinction over distances of several millimetres but on closer inspection they turn out to consist of aggregates of limpid optically subparallel crystals (maximum size .7 mm, commonly .2 mm or less), often arranged around strongly saussuritized basic plagioclase, the An-content of which could not be determined in this thin section. In the clear crystals which often show zoned structure anorthite contents were measured varying between 23 % in the cores to 41 % in the rims. Vermicular droplets smaller than .01 mm of probably diopsidic clinopyroxene with simultaneous extinctions in groups are nearly constantly present within the aggregates of clear plagioclase (fig. 19). Hornblende, remarkably often showing idiomorphic basal sections and thus giving evidence of a preferred orientation has also been noted in these parts, whereas biotite is rare in them. Lamellar twinning on (010) and (001) is common within plagioclase. In the saussurite several components are rather coarsely crystallized; epidote and muscovite are clearly recognizable.

Potassium feldspar, of which microcline and an optically monoclinic variety with moderate axial angle have been observed, is not uncommon within the aggregates of clear plagioclase. It replaces plagioclase in epitaxic intergrowths and is also represented as grains (mostly $< .2$ mm) with optical orientations subparallel to those of the surrounding plagioclases. Clinopyroxene was never seen to occur within potassium feldspar. Apatite does not show any preference for the plagioclase or dark mineral aggregates and is present in rather thick prisms. Some tiny rounded zircons and also grains of another radioactive mineral cause pleochroic haloes in hornblende and biotite.

The second specimen of which a chemical analysis was made (481) contains more dark constituents and is coarser in grain than 866; it does not show foliation. Only differences with 866 will be listed in the following paragraphs.

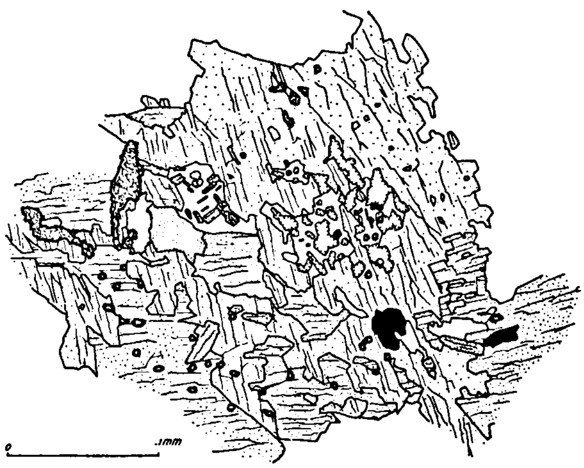


Fig. 20 Diopsidic pyroxene (barbed contours) and plagioclase (white) in green amphibole. Other minerals shown are titanite and ore. Dark-coloured biotite-amphibole rock with basic plagioclase (481).

In thin section it could be seen that green hornblende and biotite are grouped again in aggregates but less mixed than in the preceding rock. The sizes of hornblende and biotite are generally smaller than respectively 2 and .3 mm. Some large hornblendes (up to 6 mm) enclose minor crystals of the same mineral, diopsidic pyroxene, plagioclase and titanite. Where diopside occurs within hornblende, some plagioclase is mostly present too (fig. 20). The intergrowth is of the same type as in 866, but much more common in the rock under discussion. In one hornblende host several groups of parallel-extinguishing small and irregular diopside crystals could be observed, each group with an orientation different from that of the others. Titanite is abundant in the aggregates of dark minerals. It has been noted as droplets in amphibole and pyroxene, as dense clusters just as in 866 but larger (2.5 mm), and also as separate (xenomorphic) crystals up to .2 mm. Wide pleochroic haloes in biotite are not rare, but the mineral causing them could not be identified. Biotite altered locally into chlorite and prehnite and seems to have grown at the expense of hornblende in some places.

Plagioclase is represented again by aggregates (up to 4 mm) with saussuritized basic parts surrounded by masses of clear plagioclase (zoned: cores 28 %, rims up to 47 % An.). In this sample, however, diopsidic pyroxene is almost entirely lacking in these parts. Potassium feldspar is absent. Apatite prisms reach a length of 1 mm.

The following observations were made on other specimens:
The optic axial angle of the green hornblende is always well over 60°, mostly estimated between 70° and 80°. Schiller inclusions which must be inherited from a pre-existing pyroxene have been noted in one thin section. No essential differences have been observed between rocks with and without diopsidic pyroxene grains intergrown with green hornblende.
Biotite is always present in amounts subordinate to those of green hornblende. Alteration into chlorite or prehnite has been noted in several samples; in one, narrow veinlets of prehnite were recorded as well.
It was impossible to measure the anorthite content of the strongly saussuritized basic plagioclase. In rocks with less saussurite it could be seen that this basic plagioclase, with higher relief and somewhat stronger birefringence than the surrounding more acid and limpid plagioclase is also constituted of aggregates of smaller crystals with optically subparallel orientations. It is therefore very difficult to find cleavage traces. In sections perpendicular to one of the optic axes a negative character of the optic axial angle could be seen, which points to a bytownitic composition of the basic plagioclase. Inspection of the thin sections under the low-magnifying, polarizing microscope with quartz comparator revealed that some aggregates of basic plagioclase contain domains with contrasting elongations. The boundaries of these domains are extremely regular and give the impression of the aggregate having been twinned. Such features have been observed in three of the fourteen thin sections studied. In the limpid plagioclase the inverse zonarity already mentioned in the descriptions of the analyzed specimens is a constantly recurring phenomenon. As was the case with pyroxene within hornblende, no additional differences have been found between the six thin sections that contain diopside in their clear plagioclase and the remaining sections that do not.
Potassium feldspar, observed in nine rocks, is always present as microcline; in some of them an optically monoclinic variety with a moderate axial angle was recorded as well.
In one specimen spindle-shaped apatites reach lengths up to 3 mm. The radioactive mineral causing wide pleochroic haloes is probably allanite. This mineral has been determined in two specimens. One slide contains a few relatively large hypidiomorphic zircons (up to .15 mm). Quartz is totally lacking in the thin sections investigated. The chemical analyses of samples 481 and 866 are given on plate 2.

Darkcoloured biotite-amphibole rocks with acid plagioclase

The rocks to be described under this heading are generally darker-coloured and finer-grained than those of the previous type. Amphibole, biotite and plagioclase can be recognized in most of them with the unaided eye. Some plagioclases reflect light from their cleavage planes. Foliation has not been observed. Microscopically, these rocks show many similarities to those of the preceding type. The arrangement of amphibole and biotite in aggregates, the irregular aggregates of optically subparallel plagioclases, the paucity of quartz all point to a certain relationship. Yet there are also conspicuous differences as will be demonstrated below. Chemical analyses were made of four representative specimens (9, 102, 284 and 865; plate 2).
The thin sections of these rocks are not so different that it is necessary to treat them apart. Unless stated otherwise the remarks made in the following paragraphs are valid for all four rocks and therefore also for the whole group.
Green hornblende, brown biotite and titanite constitute the aggregates of dark minerals. The colour of the hornblende is somewhat darker than of hornblende in the previous group and the optic axial angle is a little smaller (estimated values between 50° and 70°). Their lengths do generally not exceed .7 mm. The interior parts of hornblendes in some thin sections are a little lighter-coloured with stronger birefringence and a somewhat larger optic axial angle than their rims. Whereas small crystals alone are present in some rocks, large and small ones occur together in others. In the latter case the larger crystals often display a fine irregular poeciloblastic intergrowth with plagioclase resembling those described in the preceding section but as a rule without clinopyroxene (fig. 21). A few altered grains of clinopyroxene were observed within hornblende in specimens 539 and 284. Biotite is only rarely more common than hornblende. Its flakes are mostly smaller than 1 mm. Titanite is very abundant in the aggregates of dark minerals as dense clusters often with rectilinear outlines and enclosing

Fig. 21 Poeciloblastic green amphiboles enclosing plagioclase, biotite and titanite. Dark-coloured biotite-amphibole rock with acid plagioclase (539-1).

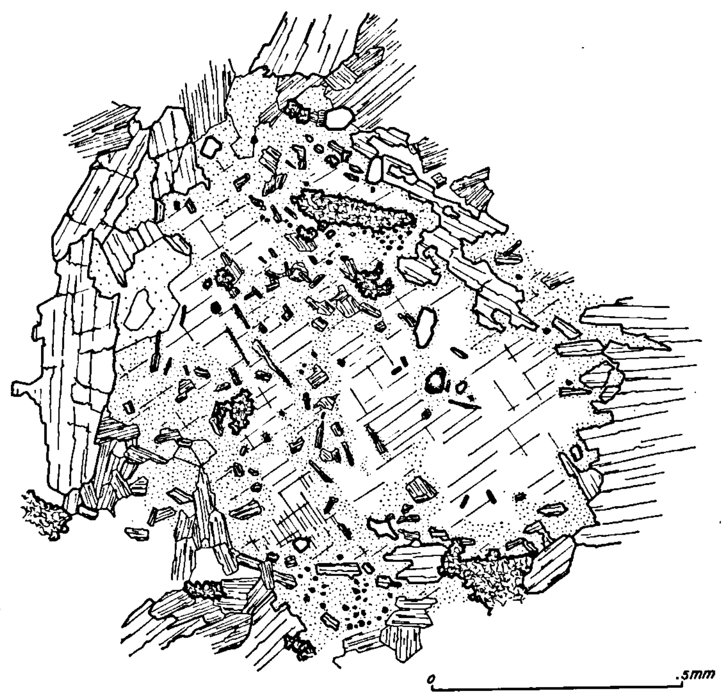


Fig. 22 Replacement of oligoclase (dotted), with inclusions of biotite, titanite, apatite (thick contour) and garnet (thick contour, dotted), by albite (showing cleavage traces). Green amphibole, biotite and titanite surround the plagioclase. Dark-coloured biotite-amphibole rock with acid plagioclase (865).

some ore, as xenomorphic individuals and as tiny droplets, all with sizes equalling those mentioned in the previous section.

As remarked above, plagioclase is represented by aggregates of optically subparallel crystals. Inverse zonal structures and saussuritized basic plagioclase are absent in this type. The highest anorthite-percentage was noted in 284: 37 %. In other rocks the measured values vary between 10 % and 30 % and show a patchy distribution. The aggregates range up to 6 mm and the crystals constituting them to .9 mm. Lamellar twinning on (010) and (001) is not always common. Hornblende, biotite, titanite and apatite are present in small amounts in the plagioclase parts. Titanite occurs as masses of droplets and acicular crystals (max. .08 mm long, less than .01 mm thick), the latter showing remarkably regular triangular arrangement in several slides. A few altered tiny clinopyroxene crystals were noticed in 539 only. In all specimens but 284 an additional phase of limpid albite has been observed within the plagioclase aggregates. The habit of this mineral varies with its quantity. When rare, it forms irregular patches within oligoclase, avoiding contact with enclosed minerals. When common, it is present as rather large crystals (1–4 mm) with simple (010) twins, still avoiding contact with enclosed minerals, which are surrounded by narrow rims of oligoclase (fig. 22). Garnet has been found in all specimens but two (539 and 284), exclusively within albite crystals and with diameters not exceeding .15 mm. The quantities of enclosed foreign minerals are smaller in albite than in oligoclase. The transitions between oligoclase and albite are always rather abrupt. In some specimens (e.g. 9) albite is more common than oligoclase. When its crystals are not too small the albites are macroscopically recognizable, because their cleavage planes reflect light very well. This albite is very similar to the albite in paragneiss (chapter VII) and orthogneiss (chapter VI); its properties point to the conclusion that it formed at the expense of more basic plagioclase. Small drops and vermicules of quartz within oligoclase have been noticed in more than half of the 17 thin sections investigated. A few individual crystals (up to .3 mm) of quartz occur in 865 only.
Small quantities of microcline were noted within plagioclase aggregates in four samples. No relation has been observed between the quartz vermicules in oligoclase and the presence of microcline. Several specimens contain small quantities of granular aggregates of oligoclase and biotite, both about .1 mm in addition to the plagioclase aggregates described above.

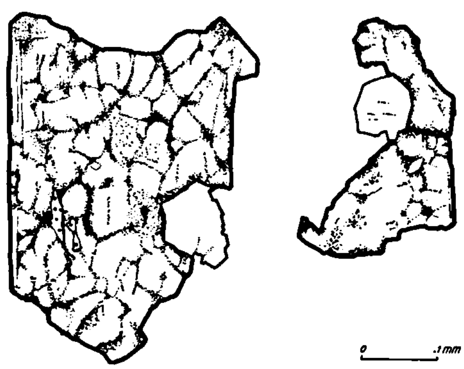


Fig. 23 Zircon enclosing apatite and some green amphibole (dotted, left individual). Dark-coloured biotite-amphibole rock with acid plagioclase (865).

Of the accessory minerals apatite is very common. Its prisms reach lengths of 1.7 mm. Zircons with idiomorphic outlines and sections up to .5 mm long have been noted in a third of the slides. Where zircon and apatite are in contact with each other it seems that apatite is the older mineral (fig. 23). Two slides contain xenomorphic zircon. Allanite in often metamict crystals up to .6 mm was found in six thin sections. When unaltered, its pleochroism is from very dark red (nearly opaque) to light brown (cf. allanite in riebeckite gneiss).

Fine-grained amphibole-rich melanocratic rocks

Nine specimens of fine-grained melanocratic rock were found within the Zamanite complex. The exposures of three of them resemble dykes with straight boundaries; the others have been found as fragments in lighter-coloured rocks. The variations between the rocks of this type are so small that they may be described together. No chemical analyses were made of them.

Macroscopically the specimens have dark greenish grey colours. Biotite, amphibole and feldspar can be recognized with a hand lens; in one sample albite is visible, reflecting light from cleavage planes. Foliation was not observed in any of the specimens.

In thin section it appears that microcline is the most prominent feldspar in all but two samples. Plagioclase (albite and oligoclase) predominates in the latter and is present in varying but minor amounts in the former rocks. In most cases microcline and plagioclase occur among each other. Occasionally, albite and oligoclase demonstrate the same relations as were described in the previous section. More often, however, albite is occurring independently or associated with microcline in epitaxic intergrowths. Oligoclase is only rarely twinned; cleavage traces are inconspicuous, irregular cracks being found instead. Albite is untwinned or with simple (010) twins. In both plagioclase-rich rocks albite is more common and larger in size (up to 1.3 mm) than oligoclase or microcline. Oligoclase in one of them is studded with tiny quartz droplets, similar to those common within plagioclase metablasts in paragneiss (chapter VII). Elsewhere quartz is virtually absent. The maximum size of microcline varies between 2 and .3 mm. When microcline is the commonest feldspar present, it is clearly larger than albite or oligoclase. The specimens 281, 764, 768, 865A and 865B, all with predominant microcline, but varying amounts of plagioclase, will be mentioned in the concluding section concerning the contact relations between rock types.

Green amphiboles and in many cases also brown biotites lie embedded in great amounts in the feldspar masses. In some rocks the dark minerals tend to be somewhat concentrated around feldspar grains but in others they are evenly dispersed throughout the rock. The absorption of the green amphibole is a little stronger than in the rocks of the previous group and the negative optic axial angles are smaller; estimated values vary between about 60° and 25° (in an albite-rich rock). The latter amphibole has a strong absorption, weak to moderate birefringence and dispersion $r > v$. The pleochroic scheme is: γ: blue-green; β: green; α: yellowish brown. These properties are indicative of a ferrohastingsitic amphibole. The amphiboles with larger optic axial angles should have compositions between common hornblende and ferrohastingsite. Until chemical analyses of these minerals are available, however, it will not be possible to establish their exact nomenclature with any degree of certainty. The maximum size of the amphiboles varies between 1 and .2 mm in the various slides. No preferred orientation of the mineral has been observed. Biotite is always subordinate to green amphibole. It is mostly found intermingled with amphibole. Two specimens (281 and 865B) show spots, a few mm across, consisting of oligoclase with some biotite, titanite and apatite. Elsewhere in these rocks biotite is almost lacking. Maximum sizes between .8 and .2 mm have been noted.

Grains of titanite, up to .15 mm are present everywhere and in large amounts in the rocks under discussion. In the cores some opaque mineral is often present. Clusters of tiny titanite crystals were observed in addition to the dispersed grains in three samples. Apatite is a constant accessory. A few idiomorphic zircons were noticed in two samples (a.o. 764), some metamict grains of allanite in another two (764 and 865B).

Meso- to leucocratic biotite-amphibole rocks

All remaining specimens, collected in the eastern part of the Zamanite-complex and not belonging to the three groups described above, are classed within this group. Since their mineral assemblages are thought to be metamorphic and foliation is only sporadically visible, the textural designation "rock" should be applied here in the same way as in the previous groups.

Various types have been distinguished under the microscope; the criteria are principally: the quantity, composition and habit of the constituting feldspars and the presence or absence of rock-forming quartz.

Quartz- and albite-poor types

In these types no significant quantities of rock-forming quartz are present. Only five specimens (337, 766A, 766B, 767, 846B) were collected, all but 337 in the neighbourhood of dark-coloured basic or acid plagioclase-bearing rocks. Macroscopically it is impossible to recognize them as a separate type. Thin sections of the chemically analyzed samples 337 and 767 will be described below.

When inspected through the low-magnifying, polarizing microscope using the quartz comparator, the feldspar masses of 337 show subparallel extinctions over surfaces up to 8 mm^2. On closer inspection these masses prove to consist of oligoclase, the grains of which rarely measure more than .1 mm, and of some blastic albite up to 1 mm. The habit of the albite is similar to that described in the two preceding groups. A few tiny garnets have been found enclosed. Quartz is occurring as rare crystals up to .3 mm and as droplets (about .02 mm) within and between the oligoclase grains. Myrmekite-like vermicules have been noticed in oligoclase; potassium feldspar, however, was not found. The green amphibole in this sample has a negative optic axial angle of about 45°–50°; in other respects it resembles the amphiboles dealt with before in this chapter. The xenomorphic crystals measure up to .7 mm; mostly they do not exceed .3 mm. Brown biotite is only a little less frequent than green amphibole and a little smaller in size. Titanite and apatite are common. The former mineral has been observed in dense clusters (up to .3 mm) of tiny grains and as separate xenomorphic crystals. Further accessories are: a few grains of metamict allanite and some idiomorphic zircons with a maximum length of .25 mm.

Other thin sections display the same picture: fine-grained feldspar masses with varying amounts of limpid albite of larger dimensions. Quartz is totally lacking in all but the chemically analyzed specimens. Microcline is present in two of them almost to the exclusion of plagioclase. Since thin sections were made of small samples 766A and B, taken from an elsewhere completely decomposed rock-face, statistically reliable chemical analyses could not be performed on them.

767 contains, like 766 A and B fragments of dark-coloured biotite-amphibole rock surrounded by the leucocratic rock. Before the sample was crushed for analysis these fragments were removed as carefully as possible. Only the leucocratic part of the thin section will be described here. Mosaics of fine-grained feldspar (individual grains not exceeding .12 mm) show subparallel extinctions in patches with surfaces of at most 4 mm^2. Oligoclase predominates, microcline is common. Blastic albite, with larger dimensions (.2–.6 mm), is rare. The rock therefore has an equigranular appearance. Tiny grains of quartz (.02 mm) are common except within albite. Measurement of the anorthite percentage of oligoclase is difficult since cleavage and twinning are mostly absent. A few garnets (max. .02 mm) lie enclosed within albite. Green amphibole ($2V_\alpha$: 55°–60°), biotite and titanite were recorded as aggregates and as separate crystals. The dimensions of the two former minerals never exceed .3 mm. Apatite is rare; idiomorphic zircons measure up to .4 mm. A few metamict aggregates of allanite were noted. The chemical composition of these rocks is given on plate 2.

Albite-rich, quartz- and microcline-poor type

Six specimens of a rock mainly consisting of oval albites and minor amounts of dark constituents will be described in the section on the biotite-amphibole rocks of the western part of the Zamanite complex, from where four of the samples, among which an analyzed one, derive.

Microcline-poor quartz-albite rocks

The nine specimens of this group, which could be recognized only microscopically, have been collected within or in the neighbourhood of the leucocratic planar gneiss with the exception of sample 843, that has been found about 300 m more to the south. All rocks of this type are leucocratic; foliation has been observed in only one of them. The description given here of sample 98 is valid for all other rocks as far as the appearance of the light constituents is concerned; the dimensions of the light minerals and the kind of the dark ones may vary somewhat.

Quartz and feldspar constitute a panxenoblastic fabric of quartz ($<$ .7 mm) and albite, generally not exceeding 1 mm and with many inclusions of smaller quartz crystals (up to .2 mm). The amount of quartz is subordinate to that of albite. The latter mineral exhibits the same twins as in the riebeckite gneiss: simple albite, albite-Carlsbad or Carlsbad twins or twins with a few wide lamellae; it seems to be a primary constituent and not a product of blastesis (oligoclase, as observed in several rocks described above, is totally absent). Only a few grains of microcline (smaller than .15 mm) occur in this sample; the mineral is a little more common in some others.

Dark constituents in 98 are: a probably ferrohastingsitic green amphibole with strong absorption, an almost uniaxial interference figure and strong dispersion (r > v) as poeciloblastic crystals up to .7 mm, and a brown biotite, pleochroic from very dark brown to yellow brown, locally arranged in radial aggregates. Both minerals are rather altered. Titanite is an accessory forming exceptionally large (up to 1 mm) poeciloblastic crystals with comparatively large optic axial angles (about 37°). Opaque mineral, in hypidiomorphic grains, is common and often associated with biotite; amphibole, biotite and titanite were noted as inclusions. Zircon is present as round grains with diameters smaller than .1 mm, often in clots and in a few cases as small turbid xenomorphic individuals. The allanite, observed in 98 is light-coloured, compared with that found in several other groups and in riebeckite gneiss. Apatite has not been noticed.

The second specimen selected for chemical analysis is 843. Study of the thin section disclosed that this rock carries some very altered light-green clinopyroxene. In other respects it is very similar to 98; only differences will be mentioned here. Most clinopyroxene has been observed concentrated around a 4 mm long group of fluorite crystals together with relatively large albites (up to 1.3 mm), devoid of enclosed quartz. Such albites are absent elsewhere in the slide. Microcline seems to be somewhat more abundant than in the section of 98 (though the K_2O values in the chemical analyses, plate 2, differ only .1 %!). The clinopyroxene is more altered into a biotite-like mineral, (partly as vesicular aggregates and limonite) than the green amphibole, which differs from the amphibole in 98 only in having a negative optic axial angle of about 30°. Fluorite has also been noted elsewhere in the section both as amoeboid and as small round grains. When adjacent to a radioactive accessory fluorite is coloured deep-purple. Tiny round grains of zircon are present everywhere, locally in clots (cf. fig. 10; 75). Opaque ore is much rarer than in 98. Finally, some apatite, one grain of pyrochlore and a few unidentified alteration products and accessory minerals were recorded.

The negative optic axial angles of the green amphiboles in the other specimens vary between about 0° and 50°. The mineral is often partly or completely altered into orange-brown limonitic material. In the latter case small unaltered crystals within albite are the only vestiges of the fact that the rock was amphibole-bearing. No amphibole at all has been detected in two specimens, both containing biotite. Muscovite is rare, once it is associated with a narrow veinlet, in a second specimen with biotite, whereas in a third it possibly came from the enclosing muscovite-rich paragneiss. As accessories the following minerals have been observed in the rocks not specifically described here: titanite, allanite (mostly with the dark red-brown pleochroism as observed in riebeckite gneiss and in some earlier groups in this chapter), zircon (small, idiomorphic, hypidiomorphic, xenomorphic and clots of tiny droplets), anatase (in stiongly altered samples, instead of titanite), fluorite, monazite and possibly xenotime.

Rocks of comparable composition but of finer grain, found at several localities NW and S of Herbille, are considered as a *fine-grained variety* of the preceding type. Microscopical investigation yielded the following data: Albite, smaller than in the rocks described in the preceding paragraphs, encloses less quartz. Subparallel extinction of groups of adjacent albites was frequently observed. The size of albite and quartz does not exceed .5 mm in one specimen; the others are inequigranular with albites up to .8 mm. The latter contain dark green amphibole with $2V_\alpha$ between 0° and 30° and dark brown biotite, both altered into limonite, biotite also into chlorite. The former rock is nearly free of biotite (only small flakes were seen in microcline) and contains light green amphibole with $2V_\alpha$ around 60°. Large poeciloblastic amphibole crystals up to 2.3 mm with many pleochroic haloes originated in otherwise inconspicuous veinlets. This sample is in contact with the dark-coloured biotite-amphibole rock with acid plagioclase, described above. The accessories are titanite (with smaller optic axial angle than in 98 and 843), some apatite, small turbid hypidiomorphic or xenomorphic zircons, altered allanite, sometimes surrounded by an epidote-group mineral, and some ore.

A few other rocks (among which 766C, to be mentioned in the section on contact relations) show the closest affinities with the samples described in the preceding paragraph, but do not completely belong to this type. They form a *fine-grained oligoclase-bearing variety.* The difference is that in these rocks some oligoclase occurs with the consequence that one doubts whether the albite is an original constituent of the rock or not. Microcline is more common than in the rocks described above, biotite is always present, green amphibole has $2V_\alpha$ between 50° and 55° and was found in one sample as small crystals in albite only. Tiny grains of garnet were observed in quartz and albite of two specimens. Titanite, apatite, hypidiomorphic zircon and some metamict allanite were noted in all thin sections.

Biotite-amphibole rocks with albite embedded in a relatively fine-grained mass of microcline, plagioclase and quartz

Nineteen samples were classed in this type. Nine of them have been collected in the western part of the area; they will be treated in the section describing that part. A summarizing description of the remaining ten, that have some characteristics in common distinguishing them from the others, will suffice, as they show only slight differences between each other. All rocks are leucocratic. Macroscopical determination of the constituent minerals is difficult, only albites being recognizable because they are big enough and reflect light from their cleavage planes. Three samples (764, 865A and 865B) contain contacts with the fine-grained melanocratic rocks described earlier in this chapter. A weak foliation, indicated by the arrangement of the dark minerals, in visible in 487 only. Chemical analyses are available of specimens 160 [1]), 470B, 487 and 865B (plate 2).

Large xenoblastic albites with diameters mostly between .3 and 1 mm and relatively few enclosed minerals are very conspicuous in thin sections of all rocks, giving them an inequigranular granoblastic appearance. The albites are untwinned, with simple (010) twins or a few broad (010) lamellae. Between these albites varying amounts of undulose quartz crystals (up to 1 mm), large microclines (max. 1.5 mm), dark constituents and fine-grained (generally $<$ .3 mm) masses of plagioclase, microcline and quartz have been observed.
In 865B large quartz is nearly absent, whereas large microcline is present in 487 only. Plagioclase in the fine-grained masses is difficult to determine. Cleavage traces are inconspicuous, the mineral is slightly sericitized and often untwinned; such twins as are present are polysynthetic on (010) and (001). When measurement was possible, values between 6 and 14 % of anorthite were found. In a few cases patches with such anorthite contents have also been observed within or along albite. The intergrowth of the grains constituting the fine-grained masses is rather regular. Quartz is smaller than the feldspars in these parts. Plagioclase and quartz in 487 occasionally show myrmekitic intergrowth. Optically subparallel extinctions of groups of adjacent individuals are not uncommon. Replacement relations have only been noticed between microcline and albite. The green amphiboles of the specimens investigated have $2V_\alpha$ varying between 50° and 0°; mostly the angle is between 40° and 50°. They are xenomorphic and reach lengths of .7 mm. One sample is amphibole-free. Dark brown biotite, altered into green biotite, chlorite and (in 487) epidote, has lengths generally not exceeding .5 mm. Titanite is abundant both as clusters of tiny grains and as xenomorphic individual crystals (up to .2 mm). Other accessories are: apatite, zircon (stout idiomorphic crystals with lengths up to .37 mm enclosing biotite, apatite and titanite), allanite, fluorite (in 487 only), limonite and opaque mineral. 470B is a transitional type to the leucocratic planar gneisses described further below. It resembles 487 but is coarser, while its albites are more irregularly shaped. $2V_\alpha$ of the ferrohastingsitic green amphibole is smaller than 30°. Biotite, subordinate to amphibole, is greenish brown. Accessories are titanite, apatite, zircon and allanite.

To conclude the description of meso- to leucocratic biotite-amphibole rocks mention should be made of a couple of samples in which the albites tend to form comparatively large (up to 22 mm^2) surfaces consisting of subparallel xenoblastic individuals enclosing only a few other minerals or differently oriented crystals of the same mineral. This phenomenon has

[1]) The analysis of 160 was made after completion of the manuscript of this chapter. The rock is very similar to the other samples.

been signalized already before and the only distinction is the extent to which it occurs in some thin sections. The properties and quantities of other constituent minerals are equal to those of various rocks cited above.

Leucocratic planar gneisses

As stated in the introduction planar gneisses are restricted to the NE part and one isolated outcrop near the southern extremity of the Zamanite complex. Foliation is macroscopically better visible than in thin section since it is visualized almost exclusively by the arrangement of the – often scarce – dark constituents. Quartz, albite and biotite are the only minerals that can be distinguished with the unaided eye. At two localities rocks considered as paragneiss xenoliths were found. Pegmatites (mostly without dark minerals) are not uncommon, while quartz veins or lenses are very abundant: paths in the area underlain by this gneiss are often full of pieces of milky white fine-grained vein-quartz.

Macroscopically the texture of the gneisses shows striking similarities with that of the riebeckite gneiss. The rocks are very inequigranular with coarser albites than were noted in any of the groups described earlier in this chapter. Though fresh samples could not always be collected the light minerals are very little altered; the dark constituents, however, appear to be completely replaced by limonite or chlorite in an extreme case. Three specimens were chemically analyzed (100, 163 and 545; plate 2).

The fabric of the gneisses is made up of relatively large albites embedded in a mostly finer-grained mass of microcline, quartz and plagioclase, also containing the dark constituents. A similar but finer-grained texture was observed in rocks of the last major type of the preceding group (a.o. samples 470B, 487 and 865B).

When inspected with a low-magnifying, polarizing microscope the albites seem to have spread like oil-films over the finer-grained masses, enclosing especially quartz crystals (generally smaller than .3 mm) which in some samples are arranged in irregular bands parallel to the foliation of the rock. The long axes of the mostly oval albites commonly measure 1–2 mm, in one specimen up to 3 mm. Twins are the same as in other albite-bearing rocks mentioned in this chapter and in the riebeckite gneiss. Narrow polysynthetic twinning on (010) has been observed in a few cases, either around enclosed minerals or as mechanical twins. Epitaxic replacement intergrowths with microcline are visible in almost every slide; it could not be established which of the two minerals is the host. Albite contains relatively few inclusions of other minerals.

Usually, the size of the grains in the feldspar-quartz masses around the albites is smaller than .5 mm, but microcline, which predominates in these portions, is rather variable: crystals up to 1 mm are present in almost all samples, larger ones (max. 7 mm) in about two-thirds of them. Cross-hatching is pronounced but not so sharp as in microclines of the riebeckite gneiss. Some perthite is nearly always present. The plagioclase in the fine-grained parts is albite or in some samples a little more basic plagioclase (up to 15 % of anorthite). It is often sericitized, polysynthetically twinned and contains more enclosed minerals (mainly biotite) than the large albites. In a few thin sections this plagioclase was found as rims around or as small patches enclosed within albite. Quartz has been observed in the albites, in the fine-grained masses and as separate undulose individuals, mostly smaller than 1.5 mm but in one rock reaching 3 mm.

Biotite is the predominant dark mineral in two thirds of the collected samples. Brown, red-brown and green-brown colours of β and γ were noted. Alteration into chlorite is common, epidote was found only once. Green amphibole occurs in one third of the slides in amounts superior to those of biotite, in another third only as tiny needles or droplets within albite and occasionally quartz. The estimated values of $2V_\alpha$ vary between almost 0° and 60°. As remarked before the amphiboles with the smallest optic axial angles have the strongest absorption and dispersion $r > v$. Irregular flakes of muscovite were found in small quantities as alteration products in three samples. Epidote has only once been noticed in considerable amount. Titanite (or in altered rocks anatase) is a nearly constantly occurring accessory, though less abundantly so than in previous groups. Comparatively large optic axial angles (about 37°) were measured in several samples. Apatite is absent in a quarter of the thin sections; zircon is nearly always represented by idiomorphic or hypidiomorphic grains with lengths up to

.2 mm. Rectangular longitudinal sections are rather frequent. In one case apatite was seen as an inclusion within zircon. Allanite with very dark red-brown colours of orange-brown and metamictic, fluorite as amoeboid or spheroidal grains and some ore are other, less frequent accessories. Garnet has not been observed in any of the thin sections.

A few remarks regarding each analyzed specimen individually follow below. 100 resembles 98 but contains coarser albites and more microcline. Accessories are: titanite, idiomorphic and hypidiomorphic zircons, apatite and some fluorite. In 163 less albite and more intermediate quartz-feldspar mass are present than is normally the case. The albites are often surrounded by sericitized rims with narrow lamellar twins. Only rarely different extinction angles of these rims and of the limpid interiors were observed. Myrmekite is present in some sericitized plagioclases; they are the only myrmekites in this group of gneisses. Other minerals are: brown biotite, a little titanite, apatite, allanite and ore. Zircon is common as hypidiomorphic crystals and as small turbid xenomorphic grains. Of the three analyzed specimens 545 is the one with the most conspicuous additional phase of sericitized and polysynthetically twinned plagioclase. Many small biotite flakes are enclosed within this plagioclase. A composition of 11 % of anorthite has been measured, but more acid compositions seem to be present as well. Dark brown biotite, altered into green biotite and chlorite, is the only minor constituent. Titanite, apatite, zircon, allanite, fluorite (one amoeboid patch measures 1.25 mm!) and ore are the accessories.

Amphibole-biotite gneisses and rocks of the western part of the Zamanite-complex

In contrast with the great variety of types encountered in the eastern part of the complex, the rocks of the western part, are rather monotonous, especially macroscopically. Fragments of rocks enclosed within otheıs, coarse-grained basic types and leucocratic planar gneisses are absent for instance.

Good exposures are even rarer than in the eastern part. Most specimens were collected as loose-lying pieces in paths. The rocks weather to fertile soil as is the case in the area SW of Zamanes. Enough water is available to permit intensive cultivation.

Amphibole-biotite gneisses with relatively coarse quartz and albite in a fine mass of feldspar and quartz

Rocks of this type are found immediately west of those described so far in this chapter: between the hill 485 m, west of Herbille, and Saramagal. Specimens are greyish or brownish coloured with an inconspicuous foliation in most of them, brought out by the planar arrangement of dark constituents. Often these minerals are concentrated in elongate patches. It is nearly impossible to recognize otheı constituent minerals than biotite with the unaided eye.

Thin sections show the gneisses to be inequigranular with xenomorphic undulose quartz crystals (maximum diameters between .5 and 2 mm) and varying amounts of xenomorphic limpid albite (diameters between .5 and 2.5 mm) in a mass of much finer grain, generally not exceeding .15 mm, consisting of microcline, plagioclase and quartz.

The textures in these masses are variable: granoblastic ones predominate in some rocks, whereas in others ıhe minerals display a complex implication fabric in which it is often hardly possible to locate grain boundaries of minerals. Especially of microcline it is difficult then to establish whether it is present as large grains surrounding the other components or as small grains with only subparallel orientations. The plagioclase of the fine-grained masses is predominantly oligoclasic; exact determinations are difficult because of sericitization and very narrow lamellar twinning. Anorthite contents above 15 % were not found. Myrmekitic quartz was sometimes observed in this plagioclase. The myrmekite-bearing plagioclases are not always in contact with microcline. Very small quartz with a diameter below .03 mm is common in both oligoclase and microcline. A little very fine perthite is often noted in the microcline. In addition to oligoclase, albite is also represented in the fine-grained portions. Its size varies from fine-grained, like the other minerals, to that of the porphyroblastic albites mentioned above. Slightly more basic albite or oligoclase is sometimes present around them or around enclosed dark minerals. The minerals of the fine-grained masses show subparallel extinctions over areas of generally not exceeding a few but in one slide up to 15 mm^2.

In many specimens the dark minerals lie mainly in concentrations between the fine-grained aggregates, quartz and albite, in others they are more evenly distributed. Biotite is always present, green amphibole nearly always (at least in unaltered rocks, see below). In most cases the quantity of biotite is larger than that of amphibole. The flakes are rather thick and xenomorphic with dark brown colours of β and γ; alteration into chlorite is common. Green amphibole, also xenomorphic, is rather dark-coloured, its absorption increasing with decreasing $2V_\alpha$, as was observed before. Optic axial angles are always under 55°. Amphibole seems unoriented, biotite does not generally show more than a weak preferred orientation parallel to the foliation; both minerals rarely exceed 1 mm in length.

Titanite, mainly in dense clusters with in a few cases some enclosed ore, is very common. When amphibole and biotite occur in concentrations, this mineral occurs associated with them. Apatite is also abundant. Zircon is much smaller and less well-developed than in previous groups; in some thin sections it could not be identified with certainty. Basal sections are often square but longitudinal sections mostly hypidiomorphic or xenomorphic. Allanite, with very dark red-brown colours is present in a more or less altered state in half of the 23 specimens investigated. Ore was found only in the cores of some titanites. Fluorite, epidote and garnet were encountered only sporadically.

Chemical analyses were made of three specimens of this group: 72B, 114 and 283 (plate 2). The amount of large albite decreases in the order of quotation. Characteristics other than those given above and pertinent to the individual samples alone follow below.

In 72B the dark minerals biotite and green amphibole, of which the first predominates, are evenly distributed. Biotite has β and γ dark-brown coloured and is oriented weakly parallel to the foliation. Green amphibole has $2V_\alpha$ of about 50°; it is often surrounded by biotite, whereas the opposite was not seen. Large and limpid albites (max. 1.3 mm) are numerous, quartz crystals (up to .6 mm) somewhat less. Both lie embedded in a fine-grained mass of microcline, oligoclase, albite and quartz. The components of this mass are in rather complex intergrowth with each other, less irregular than in 283 and less regular than in 114. Albite is often surrounded by rims of oligoclase and in turn encloses some small patches of it. Once about 7 mm^2 were seen to have subparallel extinction, elsewhere it is also common, but over smaller areas. Titanite is very common as dense clusters and as clouds of tiny droplets. Apatite in considerable quantities, a few crystals of epidote, altered allanite and zircon (hypidiomorphic to xenomorphic) are the accessories.

As remarked above the fine-grained mass in 114 shows much less implication intergrowth than that of the two other analyzed samples. The fabric is in the author's opinion best characterized as inequigranular granoblastic and is composed of microcline, oligoclase, quartz and albite. Subparallel extinctions were observed over not more than 2 mm^2. Myrmekite and quartz droplets are less common than in 283. Some microclines reach lengths of .5 mm; the rims of enclosed plagioclase grains are more acid than their cores. A few limpid albites (max. .4 mm) were noted; undulose quartz ranges up to .8 mm. The dark constituents are concentrated in oval aggregates. Biotite with β and γ dark greenish brown shows a tendency to be oriented parallel to the foliation. Green amphibole is less common; it has $2V_\alpha$ of about 35°. Titanite, again abundant, forms dense clusters or individual crystals. The mineral is mainly associated with the amphibole-biotite aggregates. As accessories were noted: apatite, hypidiomorphic to xenomorphic zircon (max. .15 mm) and altered allanite.

Specimen 283 is devoid of large albites. The mineral is only present as small crystals in the fine-grained masses. These, with subparallel extinctions over areas of less than 3 mm^2, are further composed of microcline, oligoclase and quartz in very implicated intergrowth. Quartz droplets with simultaneous extinction in groups, and myrmekites are common within oligoclase. Microcline, oligoclase and albite are so completely mixed that it is not possible to trace the boundaries of individual grains within portions with subparallel extinction. Major quartz crystals reach a length of .5 mm. They are less numerous than in the two preceding samples. The dark constituents are evenly distributed with biotite oriented parallel to the foliation. This mineral shows dark greenish brown colours of β and γ and surrounds green amphibole. Green amphibole, subordinate to biotite, has $2V_\alpha$ of about 30° and strong absorption. Of titanite dense clusters, crystals and clouds of tiny droplets have been observed. The mineral is enclosed within all other constituents of the rock but apatite. Zircon, with apatite the only accessory, has a very remarkable habit: turbid slender prisms (up to .1 mm) and crystals with irregular outlines are common, while in some localities of the slide skeletons of zircon have been observed (fig. 24). Once zircon occurs around titanite!

A third of the specimens investigated is rather altered. Green amphiboles are generally absent; only tiny prisms or droplets of the mineral enclosed within albite and quartz and limonite aggregates with the outlines of amphiboles give evidence of the mineral having been present in these rocks. Biotite has a light greenish brown colour, encloses ore and is associated with aggregates of chlorite. Titanite is often replaced by anatase and plagioclase by a potassium feldspar with a small optic axial angle. These rocks are only found near the crossing of many paths about 750 m west of Herbille.

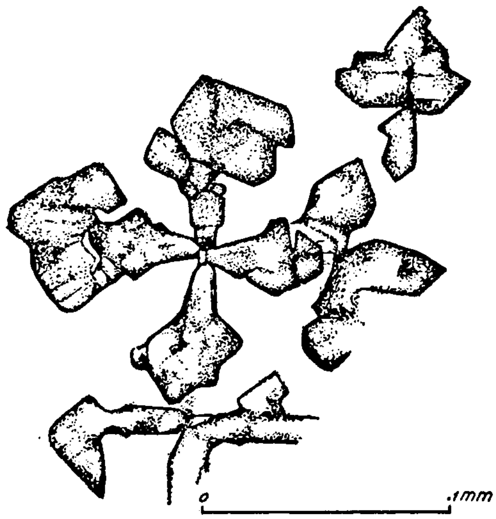


Fig. 24 Skeletons of zircon in amphibole-biotite gneiss with relatively coarse quartz and albite in a line mass of feldspar and quartz (283). Section about perpendicular to the optic axis of zircon.

Amphibole-biotite rocks with plagioclase enclosing quartz droplets

These rocks, mostly encountered in the western half of the Zamanite complex, are coarser in grain than the preceding type. Foliation is generally invisible in the specimen. The dark constituents seem to be concentrated in many rocks around feldspathic material with oval outlines and diameters up to 4 mm, just as has been observed in paragneiss. Biotite, quartz, and sometimes albite and green amphibole are the only minerals that can be recognized with the unaided eye. In one locality the rock forms the wall of a narrow, dyke-like occurrence of "fine-grained, amphibole-rich melanocratic rock" (281).

Under the microscope the arrangement of dark minerals, mainly around feldspar, appeared to occur in all thin sections. The resemblance with the image presented by paragneisses is again rather striking especially at low magnifications. In detail the differences are numerous as will become clear by comparison of the descriptions given below with those in chapter VII and from the considerations in chapter IX.

Most frequently the feldspar masses are composed of plagioclase, microcline and quartz, intergrown in a complicated way with sub-parallel extinctions over surfaces up to several mm^2. The average grainsize is larger than in the preceding type which constitutes the principal difference with it. The plagioclase is mainly oligoclase with measured anorthite contents up to 18 %, but often it is difficult to determine because of sericitization, very narrow twinning (on (010), less commonly (001)) and lack of cleavage traces. It encloses small droplets or myrmekitic vermicules of quartz; the latter were also found in grains not adjacent to potassium feldspar. Albite, when present, is probably younger.

Some rocks contain rather large plagioclases (up to 3 mm) instead of the finer-grained irregularly intergrown ones just described. Microcline is present in these plagioclase too, mostly in epitaxic intergrowth. Enclosed quartz was noted as small droplets, myrmekitic vermicules and larger crystals. The two former have simultaneous extinctions in groups, the latter not. Patches of limpid albite have been observed in varying amounts. Not very intergrown microcline is found together with quartz, some plagioclase and dark constituents around the plagioclase masses or crystals mentioned above. Plagioclase enclosed within microcline occasionally shows a more acid rim. A little very fine perthite has often been noted. Undulose crystals of quartz mostly around 1 mm in size were found only outside plagioclase masses and crystals. In several thin sections these crystals are elongated parallel with the foliation of the rock. Biotite, generally more common than green amphibole, has β and γ dark greenish brown or dark brown. The flakes are weakly oriented parallel to the foliation. Both large, rather thick and small, thinner crystals are present. Green amphibole, mostly less oriented than biotite is dark-coloured, its absorption increasing with decreasing $2V_{\alpha}$. The values of the latter rarely exceed 45°. The mineral is found within biotite, whereas the opposite is never the case; it is absent in two specimens. Biotite and amphibole altered into chlorite and occasionally epidote. Titanite is very common as clusters of small crystals and as separate individuals. Of apatite, also a common mineral, stout prisms and xenomorphic crystals have been observed. Zircon is considerably smaller and less well-crystallized than in rocks described in preceding sections. Probably some rocks contain small xenomorphic droplets of zircon. They are very difficult to distinguish from tiny titanites. Other accessories in most samples are: dark red-brown allanite, often altered, epidote (as alteration product of biotite, plagioclase and amphibole, and as rim around allanite) and ore, only once in rather large crystals, mostly enclosed within titanite. Fluorite was noticed three times, garnet (one crystal of .08 mm in albite) and carbonate (in plagioclase) each in one slide only.

Chemical analyses are available of three rocks (178, 179, 187; plate 2). The former two and 180, to be described in a subsequent section, were collected in the given order along a path leading from Zamanes to the riebeckite gneiss band of Vilaverde. Only differences with and additions to the general description will follow below.

The plagioclases of 178 are of the second type mentioned above: large, with quartz droplets (smaller than .03 mm), vermicules and crystals (< .3 mm) but with relatively few and small dark minerals enclosed. Plagioclase is partly replaced by microcline in epitaxic intergrowth. Finer-grained granoblastic aggregates of microcline, quartz (up to .6 mm), some plagioclase, biotite and green amphibole surround the plagioclases. Preferred orientation of dark minerals is inconspicuous, while they do not indicate a foliation by their arrangement either. Biotite, dark brown, is present in flakes up to .7 mm, green amphibole (much less than biotite, $2V_{\alpha}$ about 35°) in xenomorphic crystals up to .8 mm long. Accessories are titanite (no clusters of tiny crystals but groups of individuals up to .15 mm), apatite, zircon (no unambiguous observations) and some fluorite.

179 is more clearly foliated than 178: biotite is weakly preferentially oriented, plagioclases are oval with longest axes parallel, quartz is arranged in discontinuous irregular bands like biotite and green amphibole. Plagioclase, up to 2 mm, with less quartz droplets than in 178, irregular cracks instead of cleavages and microcline in epitaxic intergrowth, contains some patches of limpid albite, untwinned or with simple (010) twins. The fabric is somewhat less regular than in the preceding specimen. Biotite is greenish brown, green amphibole ($2V_{\alpha}$ about 35°) less common than biotite. Titanite occurs in dense clusters (diameters up to .35 mm) of tiny crystals associated with biotite and green amphibole. Hypidiomorphic to xenomorphic zircons up to .1 mm (enclosed within biotite), apatite and altered allanite are the accessories.

187 has been selected for chemical analysis because it seems to contain most albite of all specimens of this type. Relatively large albite (max. 1.5 mm), surrounded by and enclosing oligoclase with droplets and vermicules of quartz, seems to be the youngest feldspar present. The rest of the feldspar is irregularly intergrown, with subparallel extinctions of surfaces of about 1 mm^2, as outlined in the general description above. Oligoclase and albite predominate in the parts rich in dark minerals, whereas microcline is abundantly present together with quartz and minor amounts of plagioclase in the light coloured parts, between the large albites. Foliation is brought about by the arrangement of the dark minerals and by a weakly preferred orientation of biotite. Green amphibole is not so abundantly present, that sections favourable

for the estimation of $2V_\alpha$ could be found. The absorption is strong. Outside the feldspar masses crystals reach .7 mm; slender needles were often noted within albite. Dark brown biotite is mostly smaller than .5 mm. Titanite, in clusters and as separate crystals is associated mainly with dark minerals. Accessory minerals are: apatite, altered allanite surrounded by rims of epidote, and small xenomorphic zircon.

Five specimens with coarser feldspars and also microscopically somewhat different properties (though not sufficiently different to consider them as a new type) were collected in an area about 750 m S to SSW of the church of Zamanes. Foliation is absent, three rocks show oriented biotites in thin section. Two samples were chemically analyzed (238, 240; plate 2).

238 is unfoliated and the only sample devoid of quartz. Plagioclase (up to 4 mm) is strongly sericitized and replaced by microcline in epitaxic intergrowth. Microcline is also present in granoblastic mosaics of grains smaller than .3 mm with biotite between the large feldspars. Green amphibole is much more common than biotite. The axial angle is about 40°. The strongly xenomorphic crystals reach lengths of up to 2.3 mm. Biotite is greenish brown, much smaller than amphibole and unoriented. Alteration products of both minerals are chlorite and epidote. Titanite (up to .25 mm) is more idiomorphic than in any other specimen found in the mapped area. Apatite and altered allanite, but not zircon, were noted as accessories.

Quartz is present in 240. The crystals are somewhat elongated, up to .8 mm long and undulose. Smaller crystals were noted in a few patches of granoblastic mosaic with microcline and some biotite (all minerals generally $< .3$ mm). The plagioclases have properties very similar to those of 238 and in addition enclose quartz crystals. Greenish brown biotite (max. 1 mm) is weakly oriented parallel to the elongation of the quartz crystals, especially the smaller flakes. The mineral alters into chlorite and epidote. Green amphibole is scarce. Titanite is represented in this sample by clusters and separate crystals, ore is enclosed within some titanite crystals. Apatite was not seen, while allanite and zircon have the same properties as in the other rocks of this group.

Generally, the size of the plagioclases, the extent to which they were replaced by microcline and the less numerous quartz droplets and vermicules within them distinguish these rocks from the normal ones, dealt with in the preceding section. Determination of the plagioclases is very difficult, because of sericitization and obscure cleavage traces. Its estimated composition is albite to acid oligoclase. A few limpid albite patches were seen in the three samples that were not analyzed. $2V_\alpha$ of the green amphibole varies between 30° and 60°. In a few cases it has been observed that amphibole encloses biotite.

Biotite-amphibole rocks with albite embedded in a relatively fine-grained mass of microcline, plagioclase and quartz

Since very similar samples were collected in the eastern part of the Zamanite-complex, these rocks were already dealt with in the section on meso- to leucocratic biotite-amphibole rocks. A complete description of the specimens found in the western part will not be given, only specific information follows below. Chemical analyses were made of two specimens (244, 342; plate 2).

Foliation is macroscopically invisible. Some thin sections show the dark components to be inconspicuously concentrated in bands. The quantity of large albites is more variable than in the eastern rocks. In one thin section albites up to 2 mm were recorded. The slightly more basic plagioclase generation is difficult to determine or in a few cases even to recognize as such. Glide twins were noted in two sections. Large microcline is present in three rocks (a.o. 342), often with a little fine perthitic plagioclase. Epitaxic intergrowths were observed of microcline and albite; the latter mineral seems to replace the former. Large quartz is lacking in one specimen. $2V_\alpha$ of the green amphibole is different in each rock; values between 20° and 50° were estimated. Coarse biotite (up to 1.5 mm) occurs in 243; some of the large flakes are slightly bent. Biotite has grown around amphibole. The habit of zircon is strikingly different from that in the eastern rocks and constitutes one of the few criteria of distinction. They are smaller ($< .15$ mm), less idiomorphic and less numerous. Large crystals of dark red-brown allanite were noted in one sample. In the others the mineral is altered or absent. Fluorite has been recorded twice.

Albite-rich, quartz- and microcline-poor biotite-amphibole rocks

Like the rocks of the previous type, those to be described here were mentioned in the group "meso- to leucocratic biotite-amphibole rocks". Two of the six specimens were found in the eastern part of the complex, the others in the NW extremity, near Zamanes. A chemical analysis has been made of 180 (plate 2) collected near riebeckite gneiss along the same path where the analyzed specimens 179 and 178 were taken at greater distances from the riebeckite gneiss (see above). All rocks are leucocratic, unfoliated, with albites reflecting light from their cleavage planes, and with green amphibole as the predominant dark constituent. The analyzed specimen is essentially constituted by mostly untwinned oval albite, up to 1.8 mm in diameter. Enclosed within this mineral lie numerous titanites, some small quartz crystals, biotite flakes and many tiny prisms or droplets of green amphibole and possibly also droplets of pyroxene. The size of the latter ($<$ .025 mm) is too small for unambiguous optical determination. Some quartz and microcline grains, generally not exceeding .3 mm, surround the albites. Locally quartz aggregates with grains up to 1 mm were noted. Green amphibole (max. length .5 mm, $2V_\alpha$ about 35°, in places completely altered into limonite), titanite, biotite (greenish brown colours of β and γ, $<$ .3 mm) and apatite are also present between the large albites. Zircon has not been observed.

A similar sample, collected in the hamlet of Zamanes, distinguished itself from 180 by the larger size of albite (up to 3 mm), the absence of coarse quartz and the optic axial angle of green amphibole (about 55°).

Two other specimens of the same microscopic appearance were collected along the road Vincios-Porriño due north of the church of Zamanes. They contain some relatively large zircons with idiomorphic outlines, more microcline and larger dark constituents. The albites are nearly devoid of enclosed minerals. Green amphibole has $2V_\alpha$ about 50° in one specimen; in the other it is completely altered into limonite, and only a few needles within albite prove that the mineral was present.

The two samples collected in the eastern part of the complex, 650 m NNW of Herbille have about the same textures as the other rocks of this type. One is present as a dark-coloured fragment within fine-grained "microcline-poor quartz-albite rock" described above. The fragment has albites up to 1 mm and is surrounded by much green amphibole ($2V_\alpha$ about 45°), biotite, titanite (up to .1 mm) and some quartz, microcline and oligoclase. Enclosed within albite are countless titanites less than half the size of those outside albite and minor amounts of apatite, small needles of green amphibole and local concentrations of small biotite flakes, often embedded in oligoclase. Zircon is absent.

The other sample (768) shows a contact with fine-grained melanocratic rock, that will be described in a following section. The leucocratic part belongs to the type under discussion with albites of about 1 mm, though patches of smaller albites with subparallel extinctions over surfaces up to 3 mm^2 occur as well. The amount of titanite enclosed within albite is much smaller than in the preceding fragment. No oligoclase has been recorded in this rock. Between the albites the rock is constituted by dark green amphibole (very small $2V_\alpha$), quartz and microcline. Locally large quartz crystals of up to 1 mm lie grouped together. Titanite, idiomorphic zircon, altered allanite and some opaque mineral (within titanite) are accessory minerals.

Pegmatites

Seven specimens of pegmatite were collected within the Zamanite complex. Six are clearly discordant and often display offset of their walls. Their thicknesses do not exceed 5 cm (thicker ones, up to a few decimetres, were found but not sampled). They prove to consist of microcline, albite, quartz, apatite, biotite (only a few flakes in three thin sections), bluish grey tourmaline and a muscovite flake (both in one slide). The quantities of microcline, albite and quartz vary considerably. Microcline is always large (often exceeding 7 mm), albite and quartz were seen in all possible sizes, from masses of grains below .1 mm up to crystals of several millimetres. Albite of intermediate dimensions is commonly lath-shaped. Large crystals seem to consist of many subparallel smaller grains, grown together. Lamellar (010) twins are common, while glide-twinning on (010) is visible in several specimens. Small albites in epitaxic intergrowth with microcline were often noted around and along zones of rupture within the latter mineral.

One pegmatitic vein with a thickness of about 1 cm was found in "dark-coloured biotite-amphibole rock with acid plagioclase". It is separated from the wall rock by a 3–5 mm wide zone of green amphibole. Of this zone the 1–3 mm nearest to the vein are free from enclosed titanite and altered allanite, whereas these minerals are concentrated in the 2 mm wide band bordering the wall rock. The vein itself is constituted within the area of the thin section by one large albite (about 3 cm long) lying parallel to the walls of the vein and surrounded by smaller albites. Very narrow vein-like protuberances, somewhat more altered than the surrounding albite and consisting of albite with the same optical orientation as its host, or of epitaxic microcline occur within the large albite and have directions roughly perpendicular to the walls of the vein. Microcline is also present in small amounts around the smaller albites. Green hornblende is locally rather abundant, elsewhere nearly absent. Some chlorite and a flake of muscovite were also recorded. The pegmatites of the six samples are considered to be intrusive, whereas the last-mentioned vein is thought to have originated by lateral secretion.

The description given in the foregoing pages are the result of the study of 156 thin sections. The diversity of rock types is such, however, that nine other samples could not be allotted to any of the established groups of types either because they had the properties of more than one type or because they did not resemble any type distinguished in this work. This holds true especially for the rocks from the eastern part of the complex. Since the rocks have a very complicated history, the author is convinced that each new collection of rocks of the Zamanite-complex will yield some specimens that appear to belong to none of the mentioned groups or types or that even have to be recognized as a new group, not envisaged by him.

RELATIONS BETWEEN ROCK TYPES

It could not be detected whether the transitions between the various types of either mesocratic or leucocratic rocks are gradual, sharp or perhaps of both kinds; all the observed contact relations being between a dark-coloured and a lighter-coloured rock. Part of the dark-coloured rocks is fine-grained (third group), the rest is coarse in grain and belongs to the first two groups described in this chapter. It is remarkable that most rocks showing contact relations were found in the eastern part of the complex.

Three "fine-grained melanocratic rocks", all with little plagioclase, display sharp contacts with three different types of leucocratic rock. The first, 281, is the only one collected in the western part of the Zamanite-complex. It is present, mainly decomposed, in a path not far from riebeckite gneiss 1.5 km W of Herbille and could not be followed over a distance of more than a few decimetres. The wall rock is an "amphibole-biotite rock with plagioclase enclosing quartz droplets", somewhat perculiar in that it does not contain larger quartz crystals between the feldspars.

In the direction of the dark part the following zones were observed:

1. A fine-grained biotite-plagioclase zone, 2–3 mm wide, with grains generally below .2 mm, several adjacent plagioclases lying subparallel. The plagioclase is zonary. Anorthite contents are difficult to measure because of scarcity of cleavage traces or twins. One measurement yielded 23 % in the core to 5 % in the rim. Near zone 2 some biotites up to .5 mm were noted.
2. An amphibole-microcline zone 3–0 mm thick with amphiboles up to .7 mm, and microclines mostly well below .4 mm having subparallel extinctions in groups with surfaces of max. 1 mm^2.
3. Titanite-rich zone with biotite, zonary oligoclase and locally some amphibole and microcline (< .5 mm). This zone is 1–2.5 mm thick. Generally the grains are smaller than .2 mm but biotites of up to .7 mm were seen too.

The normal microcline and amphibole-rich "fine-grained melanocratic rock", following upon zone 3, contains some biotite in the neighbourhood of the latter. Titanite is of finer grain (generally < .05 mm) here than in the transitional zones, where it reaches diameters of up to .1 mm. The properties of the green amphiboles are the same in all parts of the specimen ($2V_\alpha$ 55°–60°, absorption not very strong).

The second sample (764) displays a sharp contact with a "rock with albites embedded in a relatively fine-grained mass of microcline, plagioclase and quartz". In the outcrop, NNW of Herbille, the "fine-grained melanocratic rock" has a dyke-like appearance. It is straight and about 10 cm thick over an exposed distance of one metre. A pink-coloured transitional band is macroscopically visible lining the contact at the side of the leucocratic rock.
Microscopically a transitional zone with biotite and zoned oligoclase resembling that of 281 is conspicuous. Most biotites (flakes generally not exceeding .25 mm) lie parallel to the contact. Again measurement of the anorthite content in plagioclase is difficult. The crystals are small (< .3 mm) and cleavage and twinning are often lacking. One measurement gave 15 % in the core and 0 % in the rim, but other crystals suggest more basic values. Locally green amphibole-microcline parts are present within this zone. The green amphiboles are larger (up to .7 mm) than within either the dark or the light part of the sample, whereas the optical properties are the same everywhere in the thin section ($2V_\alpha$ 40°–45°, rather strong absorption). Microcline reaches a length of 1 mm. Titanite is nearly absent, one idiomorphic zircon present. The "fine-grained melanocratic rock" follows immediately upon this transitional zone. It contains biotite everywhere. The contact is enriched in titanite. It turns out that the pink zone seen in the hand specimen is a band of quartz and much fine-grained microcline with subparallel extinctions in patches, situated at the light-coloured-rock-side of the transitional zone. This band is poor in dark minerals.

In the third specimen (768), found in the same area as 764, dark fragments lie embedded within a leucocratic rock that under the microscope turns out to be an "albite-rich, quartz- and microcline-poor biotite-amphibole rock". No transitional zones were seen in the thin section, only a concentration of titanite at the contact and a slightly smaller quantity of dark constituents within the light-coloured rock near the contact than at a few mm distance from it, macroscopically reflected in a light coloured rim around the fragments.

Two specimens, 865 A and B (fig. 25) found in the same area as 764 and 768, show

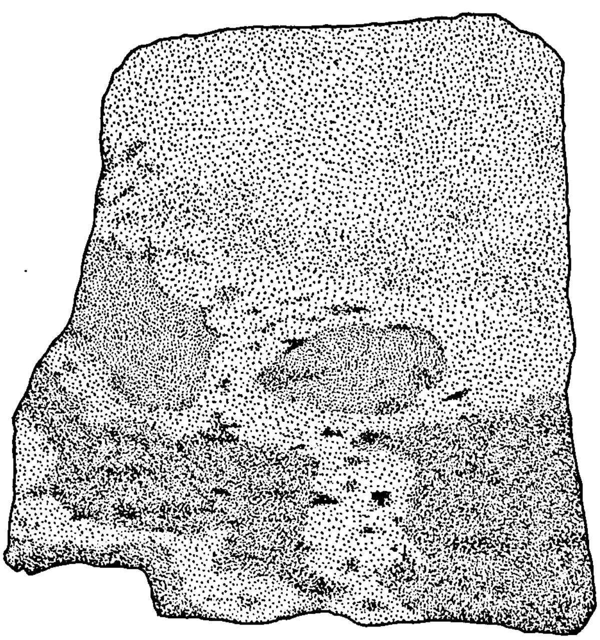


Fig. 25. Dark-coloured fragments in leucocratic amphibole-biotite rock (865 B; natural size).

"fine-grained melanocratic rock" in diffuse contact with lighter-coloured material, which under the microscope turned out to be "rocks with albites embedded in a relatively fine-grained mass of microcline, plagioclase and quartz" in both cases. The melanocratic parts proved to contain more plagioclase than those of the three specimens described above.

In the thin section of 865A the difference between both parts is best seen in the disposition of the dark minerals: in the light part they are larger and more grouped together than in the melanocratic patches where they are small and evenly distributed. Some patches consist exclusively of biotite (< .2 mm) and zoned oligoclase (< .3 mm, measured cores with 32% and 29%, rims with 21 % and 20 % An), others contain microcline (crystals up to .7 mm, grouped together, enclosing some green amphibole, others again are constituted by biotite, plagioclase (oligoclase and some albite), green amphibole, microcline and titanite. It is difficult to distinguish possible transitional types from the "fine-grained melanocratic rock" proper. When comparison with the previous samples should be permitted the biotite-rich parts would probably represent transitional assemblages, while the last mentioned variety is nearest to the "fine-grained melanocratic rock". The green amphibole has a constant $2V_\alpha$ of 45°–50°.

865B has "fine-grained melanocratic rock" constituted by green amphibole, microcline, titanite and some albite with a few patches of zoned oligoclase – biotite rock. As transitional types to the leucocratic rock are considered: discontinuous biotite – zoned oligoclase patches enclosing an idiomorphic zircon; normally zoned plagioclase (26%–17% An) – green amphibole – biotite – titanite – (microcline) patches and a part of fine-grained microcline with green amphibole (in greater concentrations than in the light part) and some small quartz crystals. The light-coloured part of this specimen has been chemically analyzed (plate 2).

Contact relations between "dark-coloured biotite-amphibole rocks with basic and acid plagioclase" and lighter-coloured rocks could be observed mainly in the area S of Herbille, though never in really fresh conditions. The most instructive examples were found in the walls of a hollow path leading from Herbille to the SSW and later turning to the west, in the last 100 metres before this path joins the path to the chapel of Virgen de las Nieves. Especially when the decomposed rock is moist the colours are contrasting and it can be observed that blocks of dark-coloured rock, the cores of which are sometimes fresh, are surrounded by distinctly lighter-coloured rock. A few fresh specimens of small dimensions could be collected (766A, B and C). In thin section the first two appeared to contain both dark and light rock. Unfortunately the samples are too small to be separated into pure light and dark parts for chemical analysis. Two loose-lying pieces with similar features were also investigated (767, 846B).

846B, collected at the junction of the two paths just mentioned is free of quartz and microcline in both parts ("dark-coloured biotite-amphibole rock with acid plagioclase" and "meso- to leucocratic biotite-amphibole rock, quartz and albite-poor type"). Biotite is concentrated in the light part along the boundary with the dark rock, which itself is marked by a characteristic not completely continuous, titanite-apatite-ore zone with some enclosed biotite and green amphibole. The width of this zone fluctuates between 3 and 0 mm. No other contact phenomena were noticed. In the light part a few dense aggregates of titanite and clusters of green amphibole or large crystals of the same resemble those in the dark part. All green amphibole has an estimated $2V_\alpha$ of 50°–55°.

767 shows "dark-coloured biotite-amphibole rock with acid plagioclase" in contact with "meso- to leucocratic biotite-amphibole rock, quartz- and albite-poor type" (chemically analyzed, plate 2) as in the previous specimen but here with microcline. The transition from dark to light part is not sharp but marked by a decrease of the quantity of dark constituents, a decrease of the size of green amphibole ($2V_\alpha$ about 55°–60°), titanite clusters and biotite flakes, by a slight increase of microcline and by the appearance of large idiomorphic zircons. Large amphiboles and clusters of titanite, like those in the dark part, lie embedded within the light part in a few places.

The small samples 766A, B and C were taken from the wall of the path already mentioned, at distances of a few cm from each other.

766A does not contain quartz or albite, the thin section shows "dark-coloured biotite-amphibole rock with basic plagioclase" in a zone of about 12 mm wide, again abruptly bounded on both sides by "meso- to leucocratic biotite-amphibole rock, quartz- and albite-poor type". The transition is characterized by the disappearance of large green amphiboles ($2V_\alpha$ probably $> 60°$), of strongly altered basic plagioclase, and of very large clusters of small titanite grains, by a decrease of the quantity of plagioclase, by a sharp increase in the quantity of microcline (with a .3 mm wide zone exclusively of fine-grained microcline along the contacts) and by the appearance of large idiomorphic zircons.

766B resembles the light part of 766A. One extremity of the specimen (and its thin section) is composed of "dark-coloured biotite-amphibole rock with mainly acid but at one spot also strongly altered basic plagioclase". The transition is abrupt as sketched above but with a less pronounced microcline rim. In the light part of both 766A and B strongly limonitized relics of small grains of a probable clinopyroxene were noted. Green amphibole has $2V_\alpha$ of about 55°.

The specimen of 766C was collected at a somewhat greater distance from the dark-coloured rock. It contains abundant quartz. Since this rock does not contain a dark part, the reader is referred to the description of the "meso- to leucocratic biotite-amphibole rocks, type: microcline-poor quartz-albite rock, fine-grained oligoclase-bearing variety".

TABLE 14 Qualitative mineralogical composition of amphibolites

Group number	Sample number	Quartz: quantity	Quartz: "reaction drops" in plagioclase	Quartz: small crystals (± .05 mm) in plagioclase	Quartz: larger crystals	Plagioclase: quantity	Plagioclase: approximate determination (see text)	Plagioclase: fine-grained irregular intergrowths	Plagioclase: fine-grained, granoblastic	Plagioclase: larger plagioclase without quartz inclusions	Plagioclase: larger plagioclase with quartz inclusions	Plagioclase: larger, with irregularly intergrown boundaries	Plagioclase: saussurite	Amphibole: green hornblende	Amphibole: light green hornblende	Amphibole: cummingtonite	Amphibole: ragged outlines	Amphibole: preferred orientation of fine-grained amphibole	Amphibole: very small crystals	Biotite	Chlorite	Garnet	Apatite	Fluorite	Titanite	Zircon	Rutile	Opaque minerals	Hematite flakes	Epidote group minerals	Allanite	Blastophytic structure	Microporphyritic relic structure	Schistose rock	Found in ortho (O) or paragneiss (P)	Ortho (O)- or Para-amphibolite (P)
1	594	?				o	and-labr?	o		x			x	o			+[2]			+			x		x	?xr[3]	x	x					+		O	O
	596	x	x			o	and-byt?	o		x		x	x	o			+						x		x	?xr[3]	x	x	x				+		P	O
	734A	?				o	ol-labr?	o					x	o			+[2]			x	x		x		x	?xr[3]	x	x		x			+		O	O
	740C	?				o	ol-labr?	o	x	x			x	o			+[2]			x			x		x	?x	x	x	x				+		O	O
	742	?				o	ol-byt?	o		x			x	o			+[2]			+	x		x	?	x	?	x	x		x			+		O	O
	769	x	x			o	ol-labr?	o		x			x	o			+[2]			x	x		x		x	?	x	x					+		P	O
	783	x	x			o	ol-labr?	o	x				x	o			+			x		?	x		+[3]	?	x	x		x[4]			+		O	O
	773	?				o	and-labr?	o		x			x	o			+			+			x		x	?xr	x	x			x		?		P	O
	613	x	x			o	and-byt?	o			x	+	+	o			+			+	x		x		+[3]	?	x	x						+	O	O[8]
2	16	?				o	and-byt?	o							o		+	+		x			x			?	x	x				+			P	O
	20	?				o	and-labr?	o						o		x			+[1]	x								x				+			P	O
	21	x[5]				o	and-labr	+	+	x				o		x			+[1]	x	x		x		x			x				?			P	O
3	154	+	+	x[6]	x	o	and-labr?		x''	x	o			o								+	x		x	?		x			x				P	O?
	175	+	+	x[6]	x	o	ol-and?			+	+	+		o						x			x		x	?		+	x						P	O?
	16	+		+[6]	x	o	and		x		+			o											x			x							P	?
	433	+	?	x[6]	+	o	and-labr?	o		x	x	x		o			+[7]				x		x		x	?		x	x	x					P	?
	205	x		x[6]	x	o	and-labr?				o	+			o	x	+			x	x		x		x	xr		x							P	P?
	399	x		x[6]		o	and-labr?	x			o	+		o			+						x		x	?		x							P	P?
	415	x	?	x	x	o	and-labr?	+		+	x	+		o			+						x		x	?xr		x			x				P	P?
4	87	+		+	x	o	byt?				o			o		x		+		x			x			?		x							P	P
	392	+		+	x	o	byt?				o				+	o					x		x		x	?xr		+			x				P	P
	395	+		+	x	o	byt?		o		+				o	x					x		x			xr		x		x[4]					P	P
	402	x		x	x	o	byt?	+			+	+			o	x	+	+		x			x			xr		x							P	P
	508A	+		x	x	o	byt?				o				o	x	+			x			x		?	?xr		x							P	P
	403	x[5]				o	byt?	o		x		+			o	x	+			x			x			?xr		x							P	P?
	430	x		x	x	o	byt?	o			x	+			o	x	+	+		x			x		x	xr	x	x							P	P?
	431	x		x	x	o	byt?	o		x	x	+			o	x	+	+		+	x				?	xr	x	x							P	P?

1) a few larger crystals are also present
2) parts with symplectitic intergrowths present
3) often opaque minerals in core
4) around opaque minerals
5) very small amount
6) irregularly distributed
7) also "beards" of hornblende in quartz
8) later tectonized

o large amounts
\+ moderate amounts (when quantities are concerned) visible (when properties are concerned)
x small amounts
? not certain
r rounded

V. THE AMPHIBOLITES

FIELD ASPECTS

Along the boundaries of the amphibolite lenses often some differential movement took place; the schistosity and foliation outside and inside the lenses respectively are concordant or accordant (where observable). The boundaries themselves, however, were observed to be disposed at all possible angles to the schistosity planes of surrounding gneisses (fig. 26). On a few occasions folded lenses of amphibolite were seen in orthogneiss (fig. 26). When a linear structural component is visible in the orthogneiss, that direction appears to coincide with the fold axis of the amphibolite.

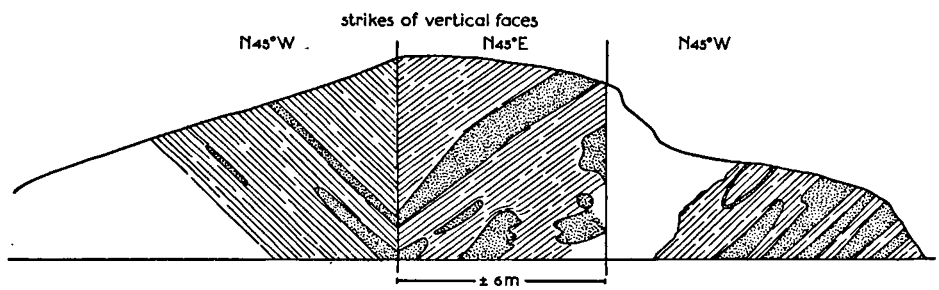


Fig. 26 Schematical drawing showing amphibolite (dotted) in orthogneiss (intersection of foliation with vertical faces of exposure indicated). Rectangular quarry along main road Vigo-Redondela.

The amphibolites occur in all rocks but the granites, the riebeckite gneisses, amphibole-biotite rocks and associated gneisses and the southernmost orthogneiss lobe E of Mosende.

PETROGRAPHY

The study of a number of thin sections of amphibolitic rocks made clear that several types can be distinguished. Not only do the differences lie in the relative abundance of certain minerals, but also in the properties of the minerals themselves. All essential data are listed in table 14. Taking into account the quartz content of the studied rocks, some represent proper amphibolites; others contain more than 10 % of quartz and should be termed quartz-amphibolites.

Due to fine grain, irregularity of intergrowth, fluctuating anorthite content, lack of cleav age traces etc., it was only rarely possible to determine the An% of the plagioclase in an other way than by measuring the sign of the optic axial angle and comparison of the refractive index with that of quartz (if present) and of the mounting resin of the thin section. Thus the very inaccurate division into andesine-labradorite (40–70 % An; opt. positive) and bytownite (more than 70 % An; opt. negative) resulted. Many amphiboles, especially the larger ones present in each slide, are nearly as broad as they are long; they have a somewhat undulose extinction due to small but abrupt changes in the orientation of the crystallographic axes in various parts of the individuals. This seems rather a growth defect than a result of tectonic influence. The boundaries of such crystals are often ragged. In their vicinity other amphiboles of smaller size occur with the same orientation. Possibly there was a tendency towards porphyroblastesis during the recrystallization of the rocks. The presence or absence of such amphiboles has been listed on table 14 in the fourth column of the amphibole section.

Rocks of the *first* group, all of which were found in orthogneisses or in paragneisses in the vicinity of orthogneiss, only contain quartz in small drops in plagioclase or no visible quartz at all. Plagioclase is mainly represented as very fine-grained irregularly intergrown masses with parts that show parallel extinction. When viewed through a microscope with low magnification the feldspar masses have very regular boundaries reflecting a micro-porphyritic relic structure (fig. 27). In fact, two shapes of relics are present when these structures are well

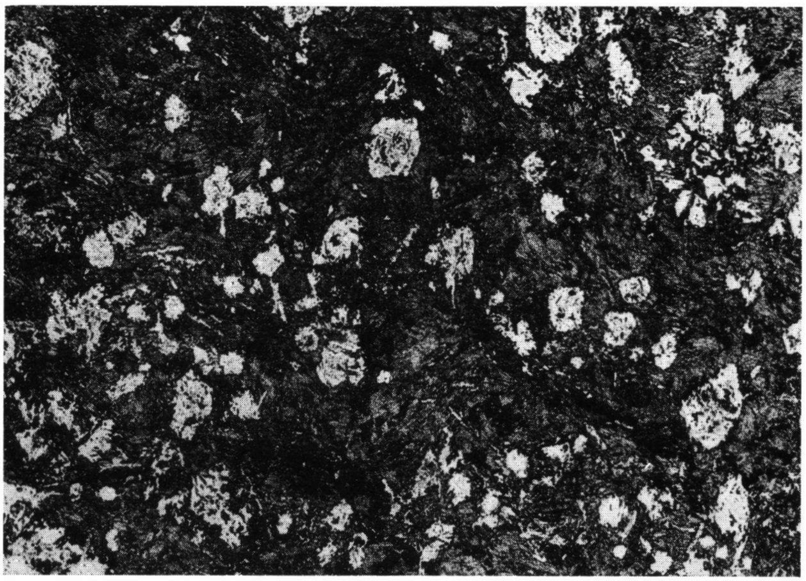


Fig. 27 Micro-porphyritic relic structure in amphibolite (740 C; ordinary light, 11 ×).

conserved: laths of aggregated feldspar without biotite or hornblende and more isometric shapes with some biotite or hornblende.

Around these masses the rock nearly completely consists of green hornblende and in a few cases some biotite. Opaque minerals with irregular outlines are evenly distributed throughout the thin section. The ratio of dark to light minerals varies between 7 : 3 and 6 : 4. Green hornblende shows very ragged, irregular crystals; in the majority of the studied samples in parts of the crystals a kind of symplectitic intergrowth with plagioclase is conspicuous. The mineral has the following pleochroic scheme: γ: bluish green, β: green and α: yellow. Biotite is pleochroic from lightbrown to almost colourless. Titanite is an important constituent in two samples only, where it often has cores of ore. In the other samples the mineral is present in tiny drops, that are hardly to be distinguished from small zircons. The column bearing on the latter mineral is therefore not very reliable. Pleochroic haloes around possible zircons were never seen. Probably the mineral is very rare in these rocks. Crystals longer than .02 mm were not observed. The presence of rutile also distinguishes this group from the others mentioned in this chapter.

Samples 773 and 613 have been put in group 1 because they have comparable mineralogical constitutions, though somewhat different aspects: 773 has no well developed relic structure; 613 is the only tectonically influenced sample in this group. The relic structure has been obliterated and there are alternating amphibole and feldspar-rich bands. The amphiboles themselves show no preferred orientation.

In the *second* group only three samples are found, one of which is doubtful, because it does not display the characteristic structure very clearly. The rocks are almost devoid of quartz. A blastophytic structure distinguishes them: lath-shaped aggregates of fine-grained plagioclase with some biotite and amphibole are embedded in amphibole masses (fig. 28). In two samples this amphibole is green hornblende in very small crystals (mostly not exceeding .075 mm) with only a few larger ones, in the third the amphibole is light green hornblende in larger crystals with ragged outlines and a not very pronounced preferred orientation. In addition to the green hornblende some needles of cummingtonitic amphibole are present in the two first-mentioned rocks.

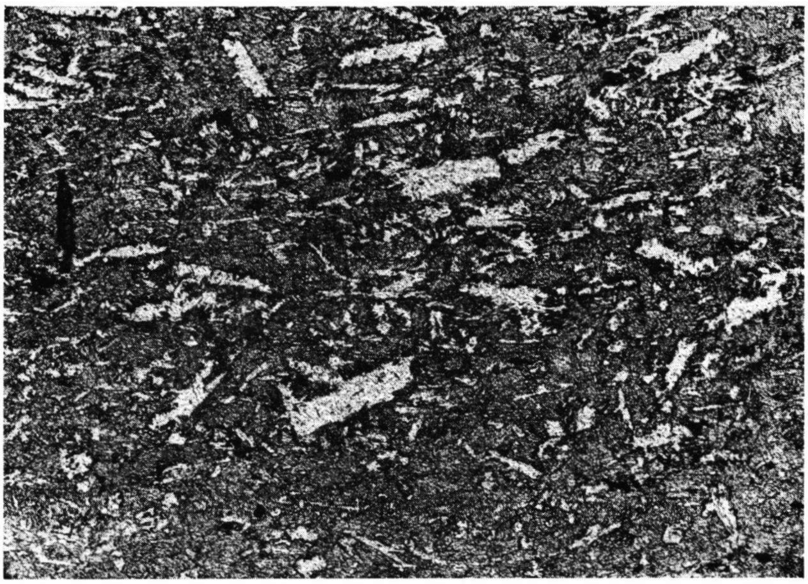


Fig. 28 Blastophytic structure in amphibolite (16; ordinary light, 16 ×).

The next seven numbers on the table belong to rocks of the *third* group, that do not have many properties in common, either with each other oı with rocks of the readily distinguishable groups. All samples contain more quartz than the previous ones.

15, 154, 175 and 205 have no fine-grained irregularly intergrown feldspar masses. Instead, the majority of the plagioclase reaches a size of 1 mm and more; in the first three samples the amphiboles are concentrated in the spaces between the feldspars. In 154 and 175 plagioclases are studded with countless quartz inclusions (smaller than .02 mm) that often show simultaneous extinction in groups. They are considered to be reaction products. Apart from these inclusions, the plagioclase also contains somewhat larger quartz crystals. Contrary to the quartz in plagioclase to be described in the last groups these crystals are irregularly distributed. 399 and 415 have irregularly intergrown fine-grained plagioclase but also considerable amounts of larger individuals. 433 is unique in its great fluctuation of the size of all its important constituents. Only 205 contains no dark but light green hornblende with some cummingtonite prisms. This thin section offers a good example of honeycomb structure. The abundance of small garnets in the plagioclase distinguishes sample 154 from any other rock described in this chapter. Small drops of titanite are present in all sections, making the recognition of small zircons nearly impossible. It is certain, however, that zircons larger than .02 mm have not been met.

Unlike the seven samples described above, the *fourth* group is not difficult to recognize. The most important distinguishing feature is the uniformly high anorthite-content. No major fluctuations of extinction angles etc. were observed. Yet it was difficult to determine the plagioclase with precision, as cleavage traces are generally lacking. In most cases one had to rely again upon the method using the sign of the optic axial angle.

The numbers 87 and 508A, representing the unequivocal members of this group, will be described first. Bytownite, up to 2 mm in diameter, with only in one sample very irregular outlines, surrounds countless quartz crystals having a diameter of about .05 mm and as a rule

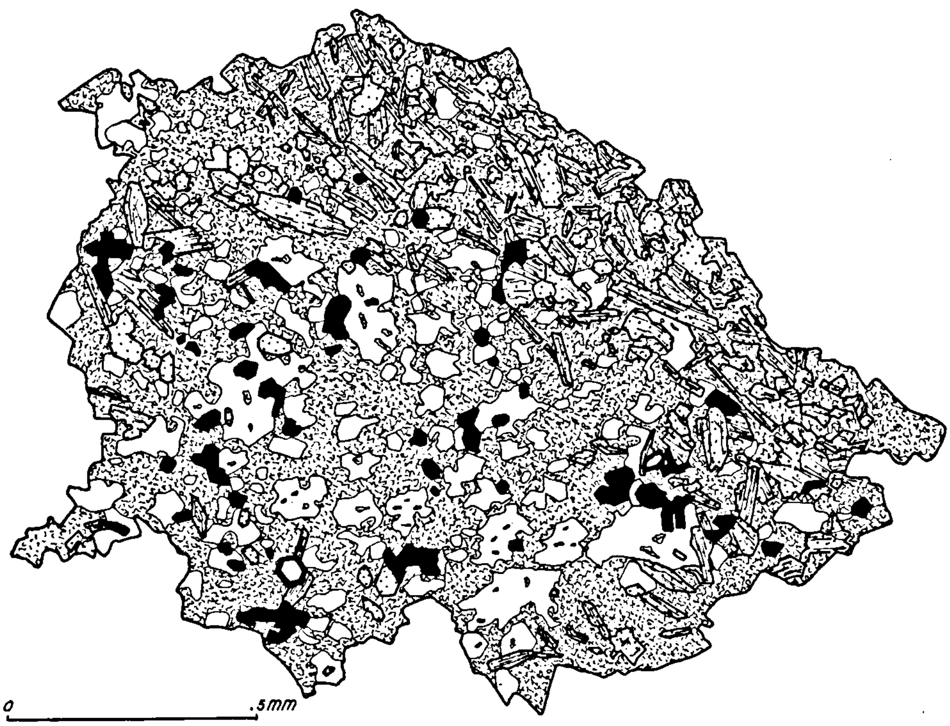


Fig. 29 Bytownite metablast in amphibolite. Enclosed minerals are quartz, amphibole, ore and zircon (thick contours) (395).

rather even grain boundaries. Occasionally a few grains of quartz seem to have coalesced. The resulting crystals show more irregular outlines than the individual small grains (fig. 29). In 395 the quartz and great parts of the plagioclase are both around .05 mm and form a very regular aggregate, whereas only locally large bytownites occupy the places of many small ones. Larger quartz ranges upwards to about 1 mm. Amphibole is more or less concentrated between the plagioclase when it is not the predominant constituent. When amphibole and plagioclase + quartz are present in about the same amounts no such distribution exists. Instead, a patchy amphibole network is embedded in the quartz-feldspar mass. This is the case in samples 87, 402 and 508A. In 395 the average ratio of amphibole to plagioclase + quartz is 4 : 6, but a banded structure is expressed by zones respectively richer in opaque minerals, amphiboles and quartz. 392 contains a great quantity of ore and the above mentioned ratio is about 3 : 7; when ore is combined with amphibole to be compared with plagioclase + quartz, the ratio is 4 : 6. All values are visual estimations.

An interesting feature of the group under discussion is the constant presence of cummingtonite. In 392 this mineral is even more frequent than light green hornblende. It was easily separated and the optical determination checked with an X-ray powder diagram (M 3085), that proved to be identical with the photograph reproduced in Niggli and Tobi (1953; p. 282). In thin sections the mineral is colourless to very light brown, forming unoriented idiomorphic prisms in other amphibole species present (fig. 30). In other cases, the latter have colourless, cummingtonitic rims; both gradual and sharp transitions were observed (fig. 30). The according to reference works characteristic twinning is weakly or not developed. The optic axial angle is either not visibly differing from 90° or slightly positive, the dispersion ($r < v$) is stronger than in the co-existing green amphiboles. The refractive indices were measured in the same material that was used for X-ray identification; α, γ and the Fe^{2+} end-member compositions deduced from these values according to several authors are listed in table 15.

The less evident members of the fourth group distinguish themselves by the fine-grained irregularly intergrown bytownite masses, that do not surround many small quartz grains.

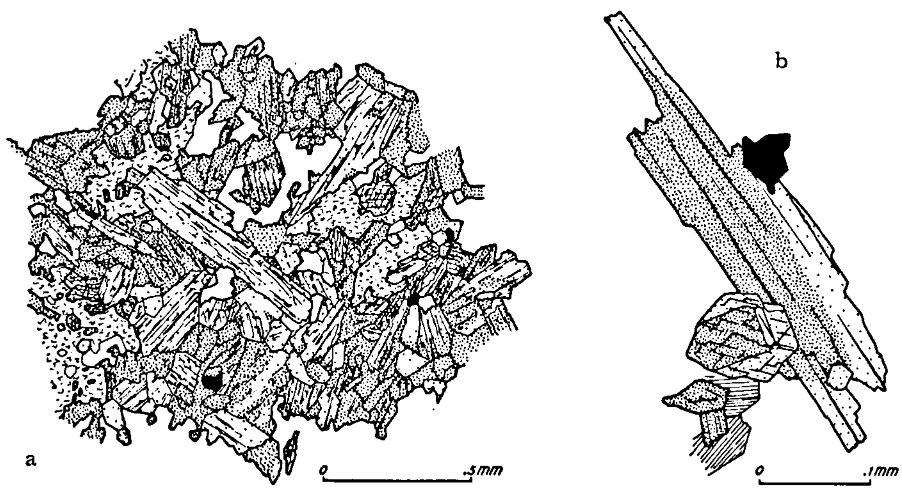


Fig. 30 Relations between green hornblende and cummingtonite in amphibolite (a: 402; b: 395).

In 403 quartz is nearly absent. In all other respects the rock resembles 402. 430 and 431 are from one locality. The first sample has a schistose appearance, the second not. Quartz is mainly restricted to patches and streaks nearly devoid of amphibole and with biotite instead, where it recrystallized to larger individuals (normally .5–.75 mm, sometimes even attaining a length of 3 mm in 430). The three samples have been allotted to this group, because, apart from the differences described above, they demonstrate a very close resemblance with samples 87, 402 and 508A. Titanite is rare, so the determination of zircon is not so dubious as in rocks of other groups. There, as stated above, the presence of larger titanites implied the possibility

TABLE 15 *Optical properties of cummingtonite* 392

α': 1.651 $\pm$ .002	measured in sodium light
γ': 1.680 $\pm$ .002	

Fe^{2+} end-member composition, deduced from refractive indices:

Tröger, 1956	: 56 %
Deer, Howie & Zussman, 1963	: 54 %
Klein, 1964	: 52 %

of the occurrence of tiny titanite drops and so made the risk of confusing these with small zircons much greater. Nevertheless the data in the zircon column should be regarded as insufficiently secure to permit any conclusion as to a possible origin of the rocks.

Chemical analyses were made of 740 and 392, table 16. The first specimen has a relict micro-porphyritic texture and derives from the same outcrop as 740C; the latter is quartz- and cummingtonite-rich and belongs to the fourth group distinguished above. The calculated

TABLE 16 *Chemical analyses of amphibolite*

	Weight per cent		Norms			
	740	392		740	392	
SiO_2	47.14	52.88	Q	—	18.3	
Al_2O_3	13.06	15.81	Ab	27.5	4.5	
Fe_2O_3	1.48	1.32	An	22.7	43.5	
FeO	13.92	12.31	Di	21.2	—	
MnO	.26	.26	Hy	2.0	27.2	$\frac{Fe^{2+}}{Fe^{2+} + Mg + Mn} = 54$
MgO	8.31	4.16	Ol	22.8	—	
CaO	9.69	8.53	Mt	1.6	1.4	
Na_2O	3.00	.52	Il	2.0	4.6	
K_2O	—	trace	Ap	.2	.5	
H_2O	.55	.90				
TiO_2	1.38	3.08	normative An %	45	93	
P_2O_5	.14	.35				
	98.93	100.12	Analyst: Mrs. H. M. I. Bult-Bik			

norms reflect very well the contrasting mineralogical compositions of both rocks (see table 14): 740 is undersaturated, contains intermediate plagioclase and no cummingtonite; 392 carries abundant free quartz, a very basic plagioclase, cummingtonite and much ore. 392 is richer in Ti than 740. It is interesting to note that the $Fe^{2+}/Fe^{2+} + Mg + Mn$ ratio in the normative hypersthene is exactly the same as the average of the ratios determined optically in cummingtonite separated from the analyzed rock (table 15). Since the formula of cummingtonite can be formed from that of hypersthene by the addition of a small amount of quartz (and some water), it becomes understandable that it could not crystallize in SiO_2-undersaturated amphibolites, like 740.

The origin of the amphibolites and the importance of cummingtonite as an indicator of the grade of regional metamorphism will be discussed in chapter IX.

VI. THE NORTHEASTERN ORTHOGNEISS COMPLEX

As already stated in the introduction, several occurrences of leucocratic planar, planolinear and linear gneiss will be described together as the northeastern orthogneiss complex. Several types could be distinguished both macroscopically and under the microscope. The distribution of these types in the field is such, that it proved impossible to draw their boundaries on the map at all accurately. In the following sections the field aspects, mineralogical composition and macroscopic and microscopic subdivision will be described.

FIELD ASPECTS

Generally, the gneisses under discussion weather less easily than the surrounding paragneisses. In consequence, they form relatively high ridges in the mapped region. Sections can be studied along the road from Vigo to the airport of Peinador and along the highway Porriño-Vigo (RN 620). Elsewhere, detailed mapping is difficult, because the gneisses are very often covered with dense young pine-forests, heather and gorse; there only big blocks of fresh greyish coloured gneiss protrude from the vegetation. In many cases it is not sure that the blocks are really *in situ*. In paths the rock is mostly weathered to yellowish brown sandy soil. Despite the weathering, the original gneissic texture is often clearly visible in undisturbed places, e.g. in the walls of hollow paths.

Dip and strike of the foliation plane of the gneisses show a great variation, but no small-scale tectonic features have been observed, not even when enclosed amphibolite lenses are folded (see below). In contrast to the changing orientation of the foliation plane, the linear fabric component commonly bears about N-S and is subhorizontal.

The distribution of the various types to be distinguished below is very irregular, but over a distance often not exceeding a few hundred metres the gneisses may appear homogeneous. Sometimes narrow "dykes" or irregular bodies of a distinct colour and grainsize occur. On closer examination they always show foliation parallel to that of the surrounding gneiss. The leucocratic, fine-grained rocks, occurring in narrow bands, with margins that make oblique angles with the foliation are interpreted by the author as original aplitic dykes. Only very rarely have xenoliths or cognate inclusions been found. In many places the gneisses enclose lenses of amphibolite. Mostly the relations between the lenses and the gneiss are not clearly visible, loose fragments of black fine-grained rock, found in paths and in the vegetation, being the only indication of the presence of the lenses. In some exposures, especially along the new highway to Vigo, west of Puxeiros, interesting examples can be observed of the way in which original basic dykes have been drawn out into boudins or lenses and folded during the gneissification of the enveloping pre-hercynian granite. No amphibolite has been observed in the southeastern orthogneissband, E of Mosende. In addition to amphibolites the gneisses contain thick veins of milky white quartz with sometimes some ore. Like the amphibolites they are mostly found as boulders. From the few observed outcrops it appears, that the quartz forms lenses and folded veins in the gneiss and is therefore older than the gneissification. The maximum observed thickness of the quartz bodies is about 50 cm.

Various younger granitic rocks, described in chapter II are intrusive into the leucocratic gneisses. The western band between Babio and Vigo shows continuous outcrops only in its southern extremity. To the north gneisses belonging to this band occur at many places in megacrystal granite, muscovite granite and medium- or fine-grained two-mica granite. Very often the gneiss blocks seem to have retained their original orientation, so they might be considered at least partly as roof-pendants or septa. Macroscopically no contact influence of the granite on the gneiss is to be seen. Good examples of gneiss in megacrystal granite are exposed on the western slope of the "Castro" of Vigo. Almost anywhere in the western half of Vigo, where an excavation is made for building, new examples can be studied. The thick central portion of the northeastern orthogneiss complex is intruded by cordierite-quartz-diorite and related granite and granodiorite in many places while a body of medium-grained equigranular two-mica granite forms a homogeneous intrusion without xenoliths or roof pendants in the southern part of the "Lonsa dome".

Quartz is always a major constituent. In some rocks plagioclase is the predominant feldspar, in the majority potassium feldspar. When their nomenclature is based on the frequency of the light minerals, the gneisses have a granodioritic to alkali-granitic composition.

MINERALOGY

Table 17 gives the qualitative mineralogical composition of the studied rock samples. Some supplementary remarks on the listed minerals follow below.

Quartz has rather weak undulose extinction and nearly always more or less indented grain boundaries. The mineral is present as very small drops in plagioclase and as individual crystals. The microscopical subdivision to be made in the next section is largely based on the distribution of the quartz crystals in the gneisses.

Plagioclase has a maximum anorthite content of 36 %. When favourable sections do not abound (e.g. too small crystals, no visible cleavage traces), the reliability of the maximum and minimum An% in the section is not great, so the author limited himself to giving the names of the plagioclase members observed. Ab-ol means that many compositions between 0 and 30 % An occur (e.g. in zoned crystals), ab + ol that younger albite is present in plagioclase with 10–30 % An. Two types of zonal variation of the anorthite content have been met: a normal zonary structure with decreasing An% towards the rims of the crystals (especially in plagioclase against microcline, but also elsewhere) and a more complex distribution, in which the lowest An% is found in a narrow zone between a basic core and a more acid rim (fig. 31). The occurrence of both structures has been listed in the table also when it was observed in a few crystals or when it involved a difference in anorthite content of a few percent only. More often, no regular, concentric variation is present but a patchy distribution of more and less acid plagioclase in a crystal. Small quartz inclusions are common in plagioclase. Sometimes, several drops show simultaneous extinction. Plagioclase-microcline intergrowths are rarely lacking in the studied sections. Plagioclase was considered to be the host, when it occurs as patchy, sericitized relics in fresh microcline. When plagioclase with locally somewhat varying extinction directions and with very narrow lamellar albite twins, that are not continuous from top to bottom of the crystal, is present in or has some inclusions of microcline, the latter mineral is taken to be the older component. Myrmekite in plagioclase bordering on microcline also offers arguments in favour of the replacement of microcline by plagioclase. *Albite blastesis.* In some rocks very clear albite is present in the plagioclases described above. When occurring as patches in older plagioclase this albite is commonly untwinned, even when the host has lamellar twins. If more albite is present the mineral shows either simple twins or twins with some broad lamellae according to the albite or albite-Carlsbad laws. The albite has less inclusions than the host plagioclase and is completely devoid of the small quartz drops so common in the older plagioclase. In rocks with abundant albite of this type, porphyroblasts or poeciloblasts of albite are to be seen enclosing quartz crystals, dark and accessory minerals, and relics of more basic plagioclase, especially around other minerals enclosed in the albite. Specimens 420 and 421 do not contain any other plagioclase than this albite, so in this respect they are very similar to the leucocratic planar gneiss described in chapter IV. An illustration of an albite porphyroblast has been given in chapter IV, fig. 22.

The extinction of *microcline* is rather wavy, the cross-hatch twinning rarely pronounced and never as striking as in the microcline of the riebeckite gneisses or leucocratic planar gneisses near Zamanes (chapters III and IV). Relations with plagioclase have been mentioned in the section regarding the latter mineral. In the microcline porphyroclasts inclusions of (hyp)idiomorphic, twinned and zonary plagioclase are rather frequently observed.

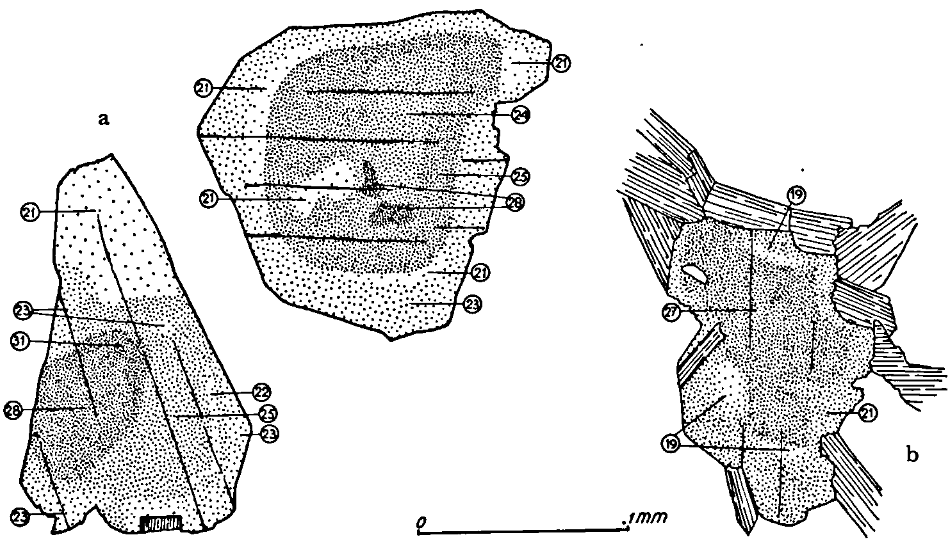


Fig. 31 Zonary structures in plagioclase of orthogneiss. Anorthite percentages measured are indicated (a: 691 B-1; b: 745-1).

Biotite was never seen as a cataclastic mineral. It appears to have recrystallized completely after the deformation of the rock. The colours listed in the table naturally show gradual transitions. As evidenced by the frequent occurrence of sagenite and sometimes of anatase, the biotite of many samples was originally titaniferous. Moreover, when titanite is present, it is always found in the biotite clusters.

Green amphibole is mainly present as poeciloblastic crystals in the feldspathic portions of the rock (fig. 32), that is outside the biotite clusters. In 622 and 821 biotite and green amphibole are associated together (fig. 33). The frequency of the mineral did not always permit the determination of 2V in sections normal to the acute bissectrix. The pleochroic scheme is: γ: bluish green; β: olive-green; α: brownish yellow. The smaller 2V, the stronger the absorption and dispersion ($r > v$). In 730 the amphibole has brownish hues in interior parts of the crystals. In composition the amphiboles will lie somewhere between green hornblende and ferrohastingsite. Remarkable is the variation in the quarry of samples 691 where in the coarse planolinear variety (691A) green hornblende ($2V_\alpha$ about 60°) is found, whereas a fine-grained linear rock from the same quarry (691B) contains a ferrohastingsitic variety with $2V_\alpha$ not exceeding about 35°. Probably the composition of the amphiboles depends on the chemical characteristics of the igneous rocks out of which the gneisses under discussion developed.

Muscovite has been encountered in only a few specimens as a primary constituent: large flakes that were bent by the tectonization of the rocks. These samples contain a subordinate

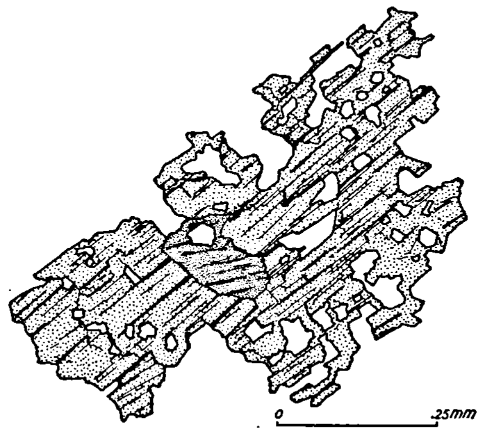


Fig. 32 Amphibole poeciloblast in orthogneiss (691A).

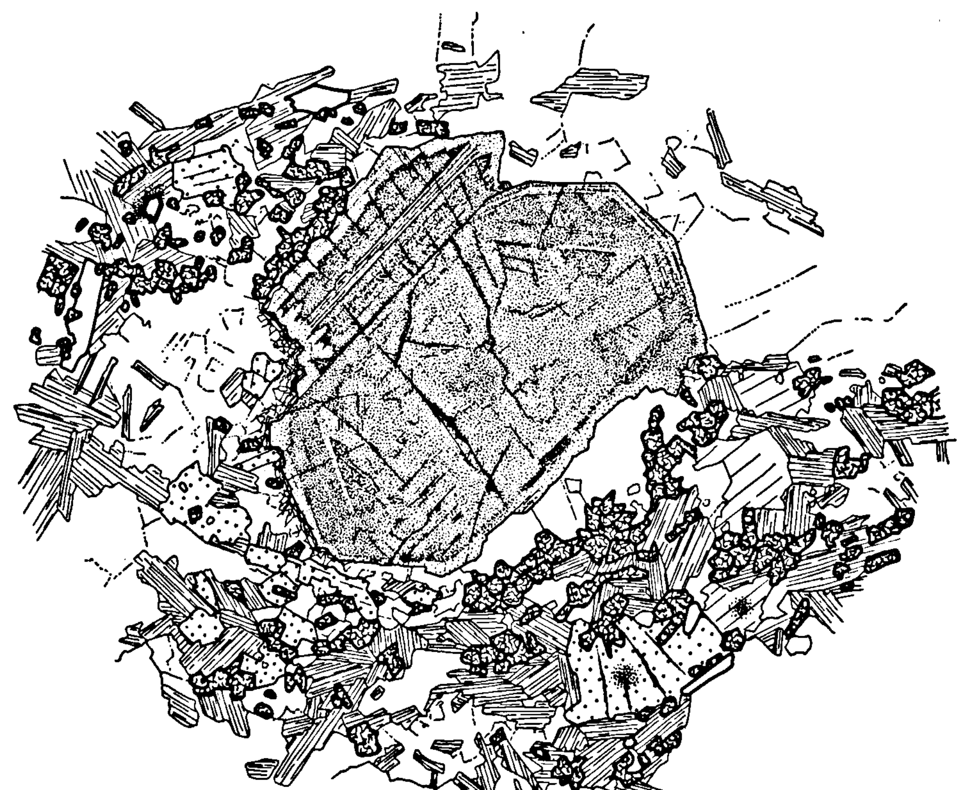


Fig. 33 Hypidiomorphic allanite surrounded by aggregate of biotite (hatched), green amphibole (dotted), titanite, with some quartz and feldspar (thin lines), apatite (thick contour) and zircon (very thick contour). Orthogneiss (622).

amount of biotite. More often muscovite is found in small quantity in the biotite-rich bands, sometimes having parallel intergrowth with biotite. Small muscovite flakes that grew during the alteration of feldspar and occur together with some sericite in nearly all the rocks of this group, were not taken into account when composing the table. Finally, in a few samples rather large and thick "books" of muscovite without any definite orientation and with irregularly frayed edges are not uncommon. These muscovite lepidoblasts have light-brown pleochroic haloes around zircon.

Garnet. If present, this mineral yields only a few crystals (or rather relics of crystals) per thin section. Little clouds of very small (< .05 mm), irregularly shaped crystals suggest recrystallized fragmented garnets, especially where these clouds have been drawn out in the direction of the foliation of the rock. They have been observed both in biotite-rich parts and in quartz-feldspar aggregates. In 723A rather large fragments of crystals (originally about

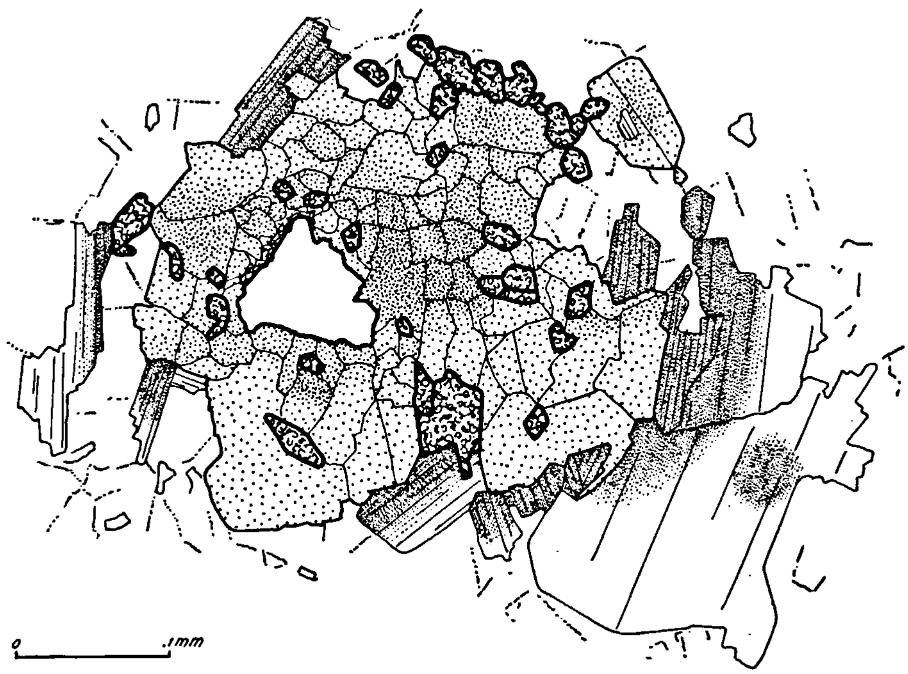


Fig. 34 Apatite (white) enclosed within aggregate of (phosphorian?, close dots) allanite. Other minerals shown are: biotite (hatched, pleochroic haloes dotted) and titanite. Orthogneiss (592).

.8 mm) were not drawn out. They are associated with green biotite, which does not occur elsewhere in the thin section. Non-fragmented crystals, sometimes idiomorphic, mostly associated with biotite reach a size of about .1 mm.

Titanite is nearly always associated with biotite. It forms xenomorphic, irregular or droplike grains, often clustered together (fig. 33). In sections perpendicular to the acute bissectrix relatively large optic axial angles were estimated, viz.: in 691A about 35°, in 622 35°–40°, in 350 45°–50°. According to Tröger (1956, p. 46) and Deer, Howie and Zussman (vol. 1, 1962, p. 74) 2Vγ widens when Ti is replaced by Fe^{3+} and Al and Ca by a.o. rare earth metals, but angles larger than 38° were not mentioned in these handbooks.

Apatite has not always been encountered. Often xenotime was found instead, so apparently yttrium, if present, formed xenotime with phosphorus before the remaining phosporus was bound to calcium in apatite.

Allanite. Most of the rocks of microscopical group I (see table) and 622 (fig. 35 b, 37b) contain some large idiomorphic allanite crystals (up to 75 mm; fig. 33), many others small allanites (not exceeding .1 mm). When fresh their colour is yellowish brown and the pleochroism weak, when metamict the colour changes to orange, while the birefringence decreases strongly. In 691B a large 2Vγ with dispersion r ≫ v has been observed. Frequently an epidote rim surrounds allanite; in biotite or amphibole wide pleochroic haloes developed in the vicinity of the mineral.
A quite different occurrence of a mineral resembling allanite could be studied in 592 (fig. 35d). In the thin section of that sample, apart from allanite as described above, many crystals of a mineral with stronger pleochroism in reddish tinges surround apatite (fig. 34). The intensity of pleochroic absorption decreases with the distance from the enclosed apatite. Like allanite this mineral causes wide pleochroic haloes in biotite. The author supposes that the "allanitic" mineral around apatite is phosphorian-allanite (nagatelite). The mineral is too scarce for separation. It will be tried to substantiate the determination with an electronmicroprobe analysis.

Zircon varies very much in size and shape. Often, the crystals are turbid. These properties as observed in thin section, are listed in table 17. No crystals larger than of .2 mm have been seen. *Fluorite* with irregular outlines is present in quite a few rocks. It is purple-coloured in the vicinity of allanite and zircon. *Xenotime* in xenomorphic grains, often with a brown rim, is found together with or to the exclusion of apatite, as stated above. *Anatase* occurs as a xenomorphic secondary mineral in biotite. *Tourmaline* is not represented by more than a few blue-green xenomorphic grains. *Epidote* is an alteration product of biotite, amphibole and plagioclase. *Chlorite* is the common secondary mineral after biotite.

PETROGRAPHY

Macroscopical subdivision

Since it was impossible to map the types of leucocratic gneiss, the author tried to subdivide the more than 70 collected samples in the laboratory, mainly taking into account grainsize and texture. The following grouping could be made:

a. Fine-grained planar gneiss. Very narrow, strictly parallel laminae of biotite (and sometimes amphibole) alternate with up to 2 mm wide bands consisting mainly of quartz and feldspar. Porphyroclasts are rarely visible with the unaided eye (fig. 35a).

b. Planar augengneiss. Like the foregoing type, this rock is composed of thin bands of dark and light minerals. The quartz-feldspar bands, however, contain feldspar porphyroclasts up to 2 cm. The dark bands bend around these porphyroclasts. Moreover, in some samples a weak linear arrangement of dark minerals in the foliation plane is visible (fig. 35b).

c. Planolinear augengneiss. A clear linear fabric is produced by the ordering of the dark minerals into flattened rods, thus indicating the presence of an additional planar component. Like group *b*, gneisses of this type are characterized by the frequent occurrence of feldspar porphyroclasts (fig. 35c).

d. Fine-grained planolinear gneiss. Just as rocks of group *c* are the planolinear equivalents of rocks of group *b*, this group includes the planolinear varieties among the fine-grained gneisses (fig. 35d).

As is nearly always the case when one tries to subdivide a natural rock-sequence, a few samples do not fit into the established groups.

Especially between groups *c* and *d* several transitional varieties had to be recognized. The subdivision having been made, it was tried to plot the different types and their mineral content, determined in thin sections, on the map. Even with all these data, it was impossible to draw any reliable boundary between types. Nevertheless, some general tendencies could be

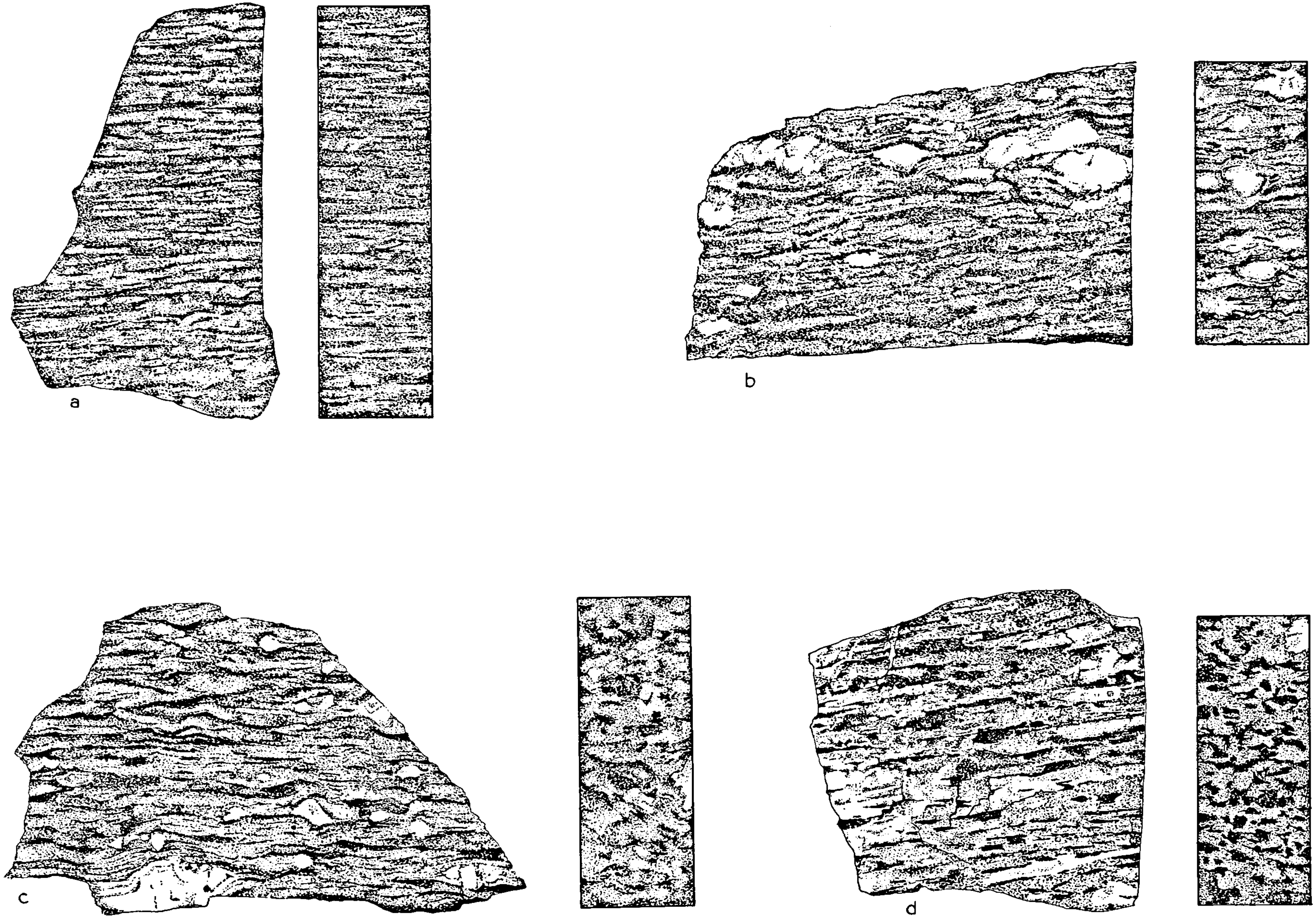
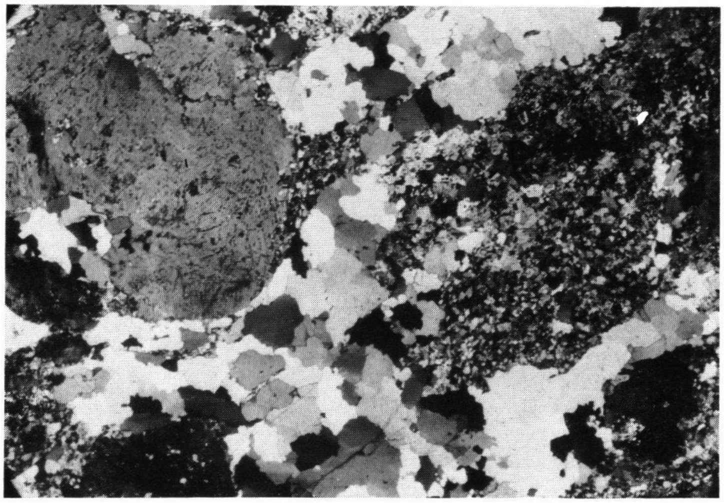
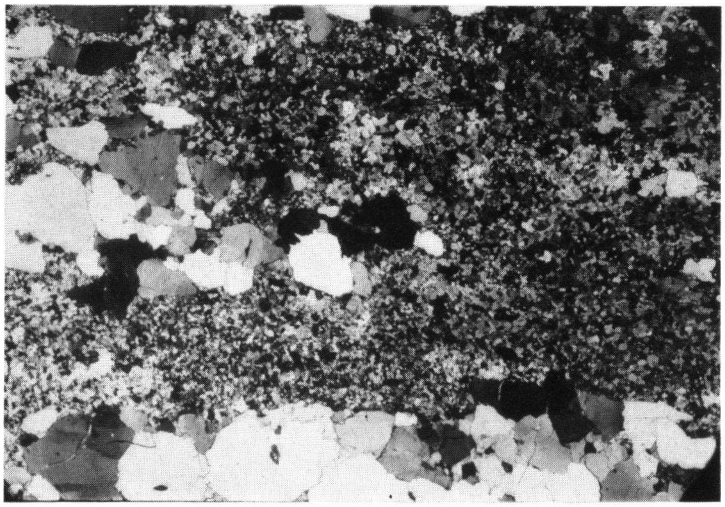


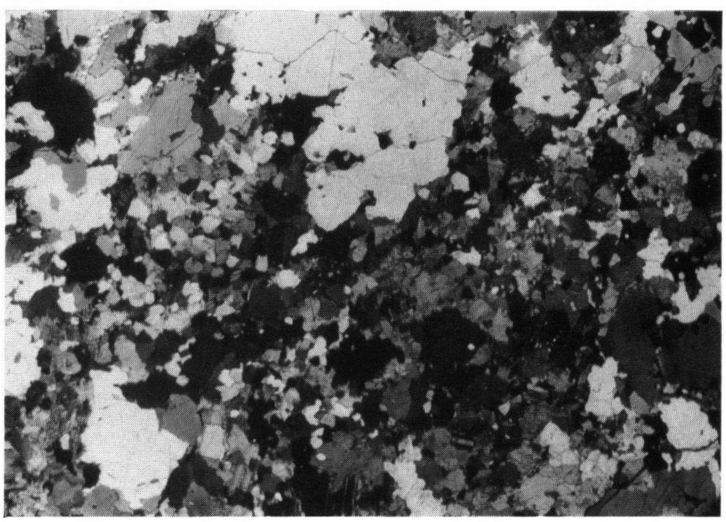
Fig. 35 Macroscopical types of orthogneiss. a: fine-grained planar gneiss (604); b: planar augengneiss (622); c: planolinear augengneiss (449); d: fine-grained planolinear gneiss (592). Rectangular drawings are perpendicular to linear component of texture (if present), irregular drawings parallel to the same. Natural size.



a

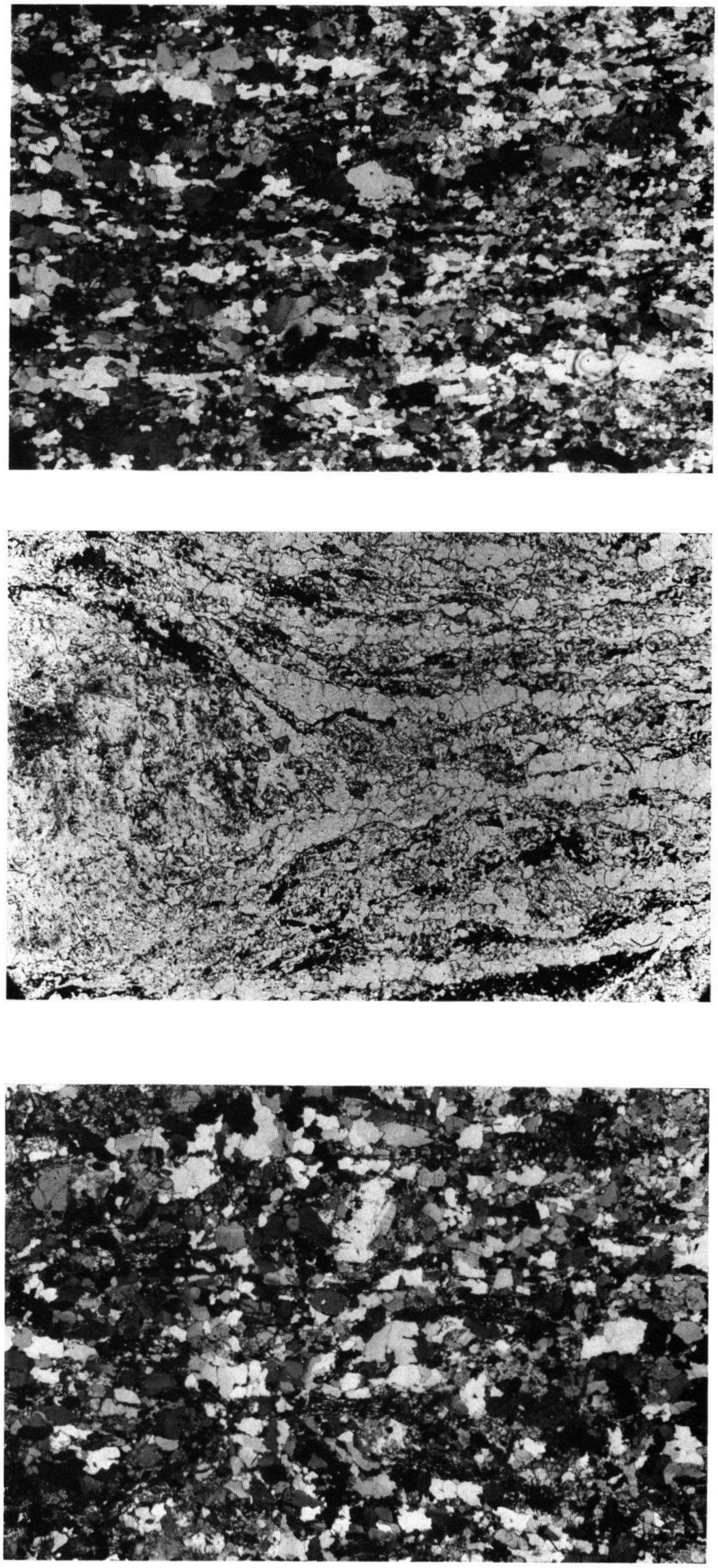


b



c

Fig. 36 Microscopical types of orthogneiss. a: group I, with microcline porphyroclasts (593); b: group I, without microcline porphyroclasts (605); c: group IA (639). Sections perpendicular to lineation; crossed nicols, 9 ×.



a

b

c

Fig. 37 Microscopical types of orthogneiss. a: group II, without microcline porphyroclasts (604-1); b: group II, with microcline porphyroclasts (622); c: group IIA (620). Sections perpendicular to foliation; a, c: no lineation visible, crossed nicols, b: section oblique to linear component of texture, ordinary light, 9 ×.

deduced: In the westernmost band fine-grained gneisses of groups *a* and *d* are rarely met. Planar augengneisses (group *b*) are observed to be the most important rock type in the western part of the large central orthogneiss body. But although texturally alike, they are varied in their mineral content. They sometimes contain e.g. big muscovite crystals, other rocks in thin section show green amphibole and titanite, the habit of the zircon crystals is different, etc. In the "Lonsa dome" the predominance of group *b* in the centre and of rocks of group *a* along the boundaries with the paragneisses is conspicuous. However, they differ in mineralogical composition in that the rocks of group *b* contain green amphibole and titanite in addition to the biotite, allanite and fluorite present in both types. The orthogneiss E of Mosende in the southeastern part of the mapped area is very leucocratic. As a consequence, its fabric is less easily distinguishable macroscopically. It is considered by the author to be most akin to the planolinear augengneisses (group *c*).

Microscopical subdivision

From the discussion above it will be clear that it was desirable to try another subdivision, viz., based on the microfabric of the rocks. Quite different groups appeared as the result of this inspection. The interrelations of the various minerals will be described here. For particularities of each mineral the reader is referred to the section on the mineralogical composition earlier in this chapter.

I is a group in which (sometimes irregular) bands of coarse quartz crystals separate portions of very fine-grained feldspar. Most rocks belonging to this group contain feldspar porphyroclasts. Nearly all members of macroscopical group *c*, a few of group *b* and one of group *d* are found back here (fig. 36a, b).

The quartz is observed frequently in crystals ranging from .5 to 1 mm with interlocking grain boundaries and undulatory extinction. In sections parallel with the linear component of the fabric the quartz forms rather straight bands; perpendicular to the lineation, however, these aggregates show up as lenses and contorted bands. It has preferred optical orientation and frequently an elongation of the grain-shape perpendicular to the direction of the seams in which it occurs. Crystals of other minerals are scarce in the quartz bands; sometimes an odd microcline crystal of about the same size as the quartz or small strings of feldspar mosaic are present.
In all rocks of this group, of which thin sections have been made, the feldspar is mainly represented in fine-grained mosaics of more or less equigranular plagioclase and microcline (usually $< .15$ mm). Of these mosaics, areas of 2–30 sq.mm prove to have a roughly parallel orientation of γ' when viewed with the quartz comparator. The microcline-plagioclase ratio varies from place to place. Epitaxic intergrowth of microcline and plagioclase is found in varying amounts, microcline probably replacing plagioclase. In these fine-grained parts quartz is present in small amounts and grains, or even wholly absent.
The porphyroclasts consist of microcline and reach a size of 15 mm. They commonly show strong undulose extinction and have sometimes yielded by rupture. Pressure shadows of quartz are not clearly represented. When broken, the fragments have been cemented with quartz and fine-grained feldspar mosaic (mainly microcline). In sections perpendicular to the lineation the porphyroclasts sometimes have a nearly circular outline (fig. 36 a).
Biotite forms clusters of undeformed crystals (in most cases not larger than .5 mm). These clusters are the main indicators of the linear or planar fabric of the rocks, but within them the biotite is without pronounced orientation. Very small biotite flakes are dispersed in the feldspar mosaics. Green hornblende, in contradistinction to biotite, occurs as xenomorphic poeciloblastic isolated crystals (up to 1.5 mm, fig. 32). Muscovite was not observed as a primary mineral in rocks of this group but only as postkinematic lepidoblasts or in small flakes as alteration products of feldspar. Titanite and allanite, when present, are normally found in the biotite clusters.

In short, the whole fabric of this type is clearly indicative of a strongly recrystallized, cataclastic rock, i.e., a blastomylonite. According to the nomenclature summarized by Buddington (1939; p. 252), the rocks should be called flasergneisses.

IA. A few samples, that resemble rocks of group I in having coarse quartz, but miss the fine-grained feldspar masses, constitute group IA. They are classed macroscopically in group *c* (fig. 36c).

Big undulose quartz crystals (sometimes exceeding 3.5 mm) do not form bands, but occur irregularly dispersed throughout the rock. No preferred optical orientation is apparent from inspection with the quartz comparator.
Feldspar mosaics are coarser than in group I, reaching about .5 mm. The parallel extinction of groups of crystals is less pronounced or even absent. The shape of the grain boundaries is rather regular. The amount of microcline-plagioclase intergrowth has been observed to vary considerably in the rocks of this group. It was impossible to decide with any degree of reliability whether microcline replaced plagioclase or *vice versa.*
Microcline and plagioclase, ranging in size from somewhat larger than the mosaics to 7 mm (microcline) and 3 mm (normally < 1 mm, plagioclase), take the place of the porphyroclasts from group I. Bent plagioclase or undulose microcline are rare.
Biotite is present in unbent crystals (grouped together in clusters indicating the relative predominance of the linear and planar components of the fabric), muscovite only as late lepidoblastic crystals or as alteration products of feldspar.

The fabric of this rock is typically inequigranular-granoblastic. Traces of cataclasis are wholly lacking. Recrystallization is thought to have played a far bigger role than in the rocks of group I. As the macroscopical fabric of rocks of both types is very similar, the strong recrystallization should be younger than their gneissification. The samples all derive from the northern part of the band between Babio and Vigo, so it does not seem unreasonable to ascribe the strong recrystallization to the influence of the megacrystal and muscovite granites that intruded into the gneisses.

The samples from the gneisses E of Mosende, forming a body rather remote from the other orthogneisses, are mineralogically very homogeneous (see table 17). In the microscopic textural classification they occupy a place somewhere between the groups I and IA.

The principal differences with either of the two groups are:
Quartz is irregularly distributed between the feldspar; grain-size of the feldspar mosaics is larger than in group I, but not the same in the various thin sections of these rocks (.2–.4 mm); some plagioclase porphyroclasts are present; the body has suffered definitely less cataclasis than the other rocks of the northeastern orthogneiss complex; recrystallization processes like epitaxic intergrowths of microcline and albite are common (contrary to the case described in group I, albite seems to replace microcline); grain boundaries are very irregular.
Large zircon crystals (up to .2 mm) resemble those of the riebeckite gneisses. In two of the four thin sections blue-green tourmaline has been observed. This mineral was not found in any of the other samples of the NE orthogneiss complex.

II. This group comprises gneisses in which narrow laminae of elongate quartz crystals alternate with feldspar-rich bands, that often contain porphyroclasts. Here, many representatives of group *a* reappear together with rocks of groups *b* and *d* (fig. 37a, b).

The somewhat undulose quartz has a length and width ranging from 1 and .4 mm in the section with the smallest quartz crystals to 2.5 and 1 mm in the slide with the coarsest quartz of this group. Although the crystals are mostly arranged in real bands, they sometimes occur irregularly dispersed through the rock, but always preserve their elongate shapes (samples 591, 691B and 753A). When feldspar "augen" are present, the quartz seams bend around them (fig. 37 b). In some thin sections a preferred optical orientation of quartz is visible. The grains show interlocking boundaries.
Between the just mentioned bands the rocks consist of feldspar, quartz and "dark" minerals.

The quartz-feldspar mass is mainly represented as an inequigranular reaction fabric showing very irregular grain boundaries and nearly always epitaxic intergrowths of microcline and plagioclase, in which both arguments for replacement of microcline by plagioclase and examples of the opposite case can be found. Locally, however, a more regular granoblastic mosaic of mainly feldspar has developed, with patches in which the crystals show about parallel extinction. In a few rocks poeciloblastic and porphyroblastic albite has formed, replacing somewhat more basic plagioclase.
The size of the "augen" reaches 15 mm macroscopically and 7 mm in the studied thin sections. They all consist of more or less undulose microcline and have lenticular outlines. In some microclines hypidiomorphic zoned plagioclases, as often found in the megacrysts of granitic rocks, are present.
The planar fabric of the rocks is accentuated by bands of biotite. Within them, the flakes have no preferred orientation relative to the foliation of the rock. Poeciloblastic green amphibole is observed in regions devoid of biotite in some samples. In others biotite and green amphibole occur together. Muscovite is a common minor constituent of rocks in this group, either as small lepidoblasts or together with sericite as an alteration product of plagioclase. Titanite and allanite are mainly associated with biotite. Some very beautiful idiomorphic allanite crystals (up to .75 mm) were observed in sample 622 (fig. 33).

From the description above it will be clear, that the differences with the rocks of group I and IA lie in the microfabric of the "light" minerals. Although the rocks have recrystallized to such a degree, that only the quartz bands and microcline porphyroclasts are indicative of their cataclastic past, they are only locally real granoblastic gneisses with 'a granular mosaic of feldspars and dark minerals'. The other condition in Buddington (1939; p. 252), viz. 'quartz in leaves or elongate lenses' is fulfilled in all rocks of this group.

IIA. This is a rather ill-defined group that resembles group II in having narrow quartz laminae. The quartz crystals, however, are not elongate in the direction of the bands. Members of macroscopically distinguished rock types *a*, *b* and *c* are represented in this group (fig. 37c).

As the crystals do not have an elongated shape, the quartz bands are much less obvious when one investigates the thin sections with crossed nicols. In all other respects, the properties of the rocks in this group are analogous to those of group II. Again, the quartz has some degree of preferred optical orientation. The feldspars have an inequigranular implication fabric with often epitaxic replacement. In some cases albite seems to be the younger component. Also, albite porphyroblasts with poeciloblastic rims have been observed. They have simple twins or a few broad lamellae after the albite and albite-Carlsbad laws. Microcline crystals with porphyroclastic properties are rare. The observed big microclines, sometimes with enclosed hypidiomorphic and zoned plagioclases, are interpreted nevertheless as relics from an original granitic rock.
Biotite is observed again in streaks, accentuating the planar or linear fabric of the rocks. Within the bands the biotites are only rarely oriented. A few samples contain muscovite in much greater quantities than biotite and in crystals up to 1.3 mm long, with a few exceptions parallel to the foliation of the rocks. They are slightly bent and have frayed edges, probably due to tectonization. In other rocks muscovite occurs as unoriented lepidoblasts.

Like the rocks of group II the gneisses of this group underwent much recrystallization. Regular mosaics and patches with parallel extinction are rare. Two samples have less interlocking grain boundaries than the others. They derive from the western band between Babio and Vigo and the difference should perhaps be ascribed to the influence of younger granites, as explained in the description of group IA.

TABLE 17 Qualitative mineralogical composition of gneisses from the northeastern orthogneisscomplex

Sample number	Microscopical group	Macroscopical group	Feldspar-porphyroclasts	Quartz	Plagioclase: composition	Plagioclase twins: kind	Plagioclase twins: on plane(s)	Plagioclase twins: quantity	Plagioclase: albite blastesis	Plagioclase: zonarity	K-feldspar: species	K-feldspar: plagioclase-microcline intergrowth	K-feldspar: myrmekite	K-feldspar: perthite	Biotite: sagenite	Biotite color: reddish brown	Biotite color: brown	Biotite color: dark brown altered	Biotite color: greenish brown	Biotite color: green	Green amphibole: frequency	Green amphibole: optic axial angle (2Vα)	Muscovite	Garnet	Titanite	Apatite	Allanite	Zircon: size	Zircon: habit	Fluorite	Xenotime	Anatase	Tourmaline	Ore	Epidote	Chlorite
194	I	c	+	+	ab+ ?ol	simple lam	(010)	+	x		mcl	x	x	x			+		x				x1)				[x]	s	rt							x
350	I	c	+	+	ab+ ?ol	simple lam	(010)	+	x		mcl	x	x	x			x	+	x	x					x	x		s m	r i							x
448–449	I	c	+	+	ol-and	lam	(010) others	+			mcl	x	x	x			+		x		x				x	x	[x]?	m	(h)i	x					x	x
592	I	d		+	ol-and	lam	(010) others	+		n	mcl	x			x	+									x	x	x	m	i	x				x		x
593	I	c	+	+	ab+ ol	lam	(010) others	x	x	n	mcl		x	x	x	x	+		x	x				x		x	x	m	i	x				x		x
605	I	c-d		+	and?	lam	(010) others	+			mcl	x	x				+			x	+	±60°			x	x	x	m	i	x					x	x
614	I	b	+	+	ab+ ol-and	lam	(010)	x	x	n	mcl	x	x	x	x		x	x	+	x			x	x	x	x	[x]	s	hi t					x		x
691A	I	c	+	+	ol	lam	(010) others	+		n	mcl		x	x	x				+		+	±60°			x	x	x	s	t r-hi	x					x	x
744	I	b	+	+	ab+ ol	lam	(010)	+	x		mcl	x	x	x	x		+			x			x			x	[x]	s	r t	x						
745	I	b	+	+	ab+ ol	lam	(010)	+	x	c	mcl	x	x	x	x		+		x				x		x	x	x	m	hi	x				x	x	x
611	IA	c	+	+	ab-ol	lam	(010)	+		n	mcl	x	x	x			+			x			x1)					m	hi					x		
639	IA	c	+	+	ab-ol	lam	(010)	+		n	mcl	x	x	x	x	+										x		m	hi		x			x		x
723A	IA	c	+	+	ab	lam	(010)	+		n	mcl	x		x			+			x			x	x				m	t r-hi		x					x
542	Mosende gneiss	c	+	+	ab	lam	(010)	+			mcl			x	x	+				+			x			x		s m	r t (h)i		x	x	x			x
747		c	+	+	ab-ol	lam	(010)	+		n	mcl	x	x	x			+						x		x		[x]	l	hi t		x	x				
749		c	+	+	ab	lam	(010)	+			mcl	x	x	x	x		+						x	x				m	hi t	x	x	x		x		x
750		c	+	+	ab-ol	lam	(010)	+		n	mcl	x		x			+			x			x					m	(h)i t	x	x		x			x
446	II	b	+	+	ol?	lam	(010)	+			mcl	x		x			+			x								m	r-hi t		x	x				x
447	II	b	+	+	ab-ol	lam	(010)	+			mcl	x	x	x			+			x						x	[x]	m	(h)i t	x	x					
587	II	c		+	ol	lam	(010)	+		n	mcl	x	x	x	x			+						x		x	[x]	s	r	?				x	x	x
591	II	c-d		+	ol	lam	(010)	+			mcl	x	x	x	x		+			x			x1)	x		x		s	r	x	x			x	?	x
604	II	a		+	ol	lam	(010)	+		c	mcl	x		x					+	x					x	x	?	m	i	x	x				x	x
621	II	a	x	+	ab	simple lam	(010)	+	+		mcl	x		x	x	+	x			x			x				[x]	l	i t	x	x	x			x	+
622	II	b	+	+	ab+ ol	lam	(010)	x	x	n	mcl	x	x	x					+		+	±35°			x	x	x	m	(h)i	x					x	x
623	II	a		+	ab-ol	lam	(010) others	+			mcl			x	x	x		+		x			x				[x]	s	r t	x	x			x	x	x
667	II	b	+	+	ab+ ol	simple lam	(010)	x	x		mcl	x	x	x			+						+			x		s	r					x	x	x
691B	II	d	x	+	ab-ol	lam	(010)	x		c+n	mcl		x	x	x				+	x	x	very small		x		x	x	s	r t						x	x
705A	II	a		+	ab-ol?	lam	(010)	+			mcl	x		x									x1)					s	(h)i t		x			x		+
728	II	a		+	ol-and	lam	(010) others	+		n	mcl	x	x	x					+	x					x	x	x	m	hi	x					x	x
730	II	a		+	ol-and	lam	(010) others	+		c	mcl	x	x		x		+				+	±60°			x	x	x	m	r						x	x
753A (light part)	II	a		+	ab+ ol	simple lam	(010)	+	x		mcl	x		x						x	x	small			x		[x]	m	(h)i t	x					x	x
821	II	a		+	ol-and	lam	(010) others	+		c	mcl	x	x				+				+	>60°			x	x	[x]	s m	r (h)i						x	x
858	II	a	x	+	ab+ ol	simple lam	(010)	+	x		mcl	x		x			x			+			x					s	hi t		x	x				
867	II	b	x	+	ab+ ol	simple lam	(010)	+	+		mcl	x	x	x	x		+			x				x	x			s m	r t (h)i		x	x				x
317	IIA	b	+	+	ab+ ol	simple lam	(010)	+	x		mcl	x	x	x	x	x		+					x1)			x		s m	t (h)i						x	x
420	IIA	a		+	ab	simple	(010)	+	+		mcl			x						x			+1)2)	x				s	r t		x					x
421	IIA	a		+	ab	simple	(010)	+	+		mcl			x					x	x			+2)	x	?	x		s	r t	x	x					x
612	IIA	c-d		+	ab	lam	(010)	+			mcl	x		x	x		+		x				x					l	i t				x			x
620	IIA	a		+	ab+ ol	simple lam	(010)	+	+		mcl	x		x	x		+			+			x				[x]	m	hi t		x	x			x	x
735	IIA	a		+	ab-ol	lam	(010)	+			mcl	x	x	x	x		+						x	x			[x]	s m	t hi		x					
780	IIA	b	x	+	ab	lam	(010)	+			mcl	x		x			x						+2)					s	hi t		x					
805	IIA	b		+	ab	simple lam	(010)	+	x		mcl		x	x					x				+2)			x		s	hi t							x

+	common mineral or property
x	mineral or property present in the thin section
[ ]	altered mineral
?	based on one determination
1)	muscovite lepidoblasts
2)	primary muscovite
n	normal zoning
c	complex zoning
s	small crystals (< .04 mm)
m	medium-sized crystals (< .16 mm)
l	large crystals present
i	idiomorphic
(h)i	(hyp)idiomorphic
r	rounded
t	turbid

VII. THE PARAGNEISSES

FIELD ASPECTS

The number of good paragneiss exposures is small. The rocks are very weathered; even along roads and in the walls of hollow paths it is often possible to break large portions with the fingers. Big, relatively fresh blocks with rounded shapes protrude locally from the vegetation in the higher parts of the area. They are erosion remnants and in some cases cordierite-bearing (e.g. on the ridge Las Pereiras, NE of Zamanes (fig. 2) and W of the "Lonsa dome", where andalusite and sillimanite are found in addition). It is often impossible to establish whether the blocks retained their original orientation. It is quite possible, but could not be proved, that the — invisible or thoroughly weathered — surrounding paragneisses have different mineralogical compositions.

Paragneisses yield soils that are more fertile than all other rocks partly because of the deep weathering and also because many springs produce enough water for irrigation. The low-lying regions are therefore intensively cultivated and fresh outcrops are even rarer than higher in the hills. Relatively good exposures can be studied along new sections of the highway Vigo-Porriño and Vigo-Redondela. The colour of the rocks is dark grey when fresh with brownish tinges when weathered. Light yellow, brown, red and grey colours have been observed in completely decomposed gneisses.

Since the paragneisses are considered to be the oldest rocks present in the area, they have been intruded by all the rocks discussed in foregoing chapters. Macroscopically recognizable thermometamorphic influences of granitic rocks have not been detected, though under the microscope some rocks suggest the existence of hornfelsic textures, especially around the orthogneisses. These features will receive full treatment in chapter IX. Special mention should be made of the amphibolites occurring in great amounts as lenses in the paragneisses. They are nowhere absent, but their frequency is greatly variable.

A great majority of the collected specimens has a fabric that is characterized by the abundance of round or oval grains of plagioclase. Their size varies from more than 5 mm to smaller than .5 mm, when it becomes nearly impossible to distinguish them with a hand lens. In most cases the plagioclase contains numerous inclusions of tiny biotite; clear crystals with simple twins are not rare in the southern half of the mapped area. Biotite, muscovite and macroscopically recognizable quartz are concentrated around the plagioclase grains. The quantities of these minerals decrease as a rule with the size of the plagioclase.

Occasionally, schistosity is hardly visible in thin section and in a few cases even in the specimen. Gneisses with the largest plagioclases (and consequently with much quartz and mica around them), mainly found NW of the Sierra de Galiñeiro, show very irregular microfolds on a centimetre scale, whereas fine-grained gneisses outcropping in paths not very distant from the blocks with the coarse gneisses have straight schistosities. The same has been observed in other parts of the area. As it is uncertain whether rocks in the blocky exposures retained their original attitudes, the fold axes of the microfolds have not been measured. If the biotites are not too small, it can be seen in the hand specimen that they have often grown at random. Bending of crystals around plagioclases is absent.

Next to this group of obviously plagioclase-rich gneisses there is a number of rocks without macroscopically recognizable plagioclase (either because the mineral is really rare or because it encloses so many quartz and mica crystals that it forms no conspicuous "eyelets" or because the crystals have a size below that of macroscopical identification).

In the field, bands of all these rocks with their varying contents and dimensions of micas, quartz and plagioclase and with straight, microfolded or unpronounced schistosities alternate with all possible relative thicknesses. Irregular recumbent folds of these bands with subhorizontal axial planes and amplitudes of at most a few metres have been observed in some road sections. Because of the poor exposures and the banded character outlined above it was impossible to map individual types of paragneiss. "Marker horizons" with conspicuously distinct compositions are absent in the area.

PETROGRAPHY

The properties of the plagioclases offer some characteristics for a schematical subdivision of the paragneisses: Under the microscope the plagioclases turn out to be metablasts [1]) with numerous inclusions. Among them, quartz is always present as tiny droplets [2]) and in most cases also as elongated or equidimensional grains many times larger than the droplets; small flakes of biotite and muscovite are common. Masses of quartz and micas in larger individuals than the enclosed crystals may surround the plagioclases; there is a gradual transition from this texture to the other extreme in which all metablasts are in direct contact with each other, enclosing the remaining minerals.

The following groups will be described:

1. Gneisses with quartz droplets and crystals in plagioclase metablasts, subdivided into rocks with: a) Small quantities of quartz and mica around plagioclase, and: b) Considerable quantities of mica and quartz around plagioclase.
2. Gneisses with quartz droplets but only a few quartz crystals enclosed in plagioclase metablasts.

The plagioclase metablasts of groups 1 and 2 are in general visible in the specimen with the unaided eye.

3. Rocks with only a few or without the plagioclase metablasts that characterize groups 1a, 1b and 2.

Special features, viz. a rock with bytownitic plagioclase, gneisses with cordierite, andalusite or sillimanite, rocks with certain fine-grained textures, albite blastesis, the occurrence of microcline, the presence of muscovite lepidoblasts, and the metasomatic enrichment in tourmaline will pass in review at the end of this chapter.

1a. Paragneisses with only small amounts of quartz and mica around plagioclase metablasts that enclose tiny droplets and somewhat larger crystals of quartz

The metablasts are rarely longer than 3 mm. Their dimensions decrease until one doubts whether the rock contains plagioclases enclosing quartz or consists of an equigranular mosaic of quartz and plagioclase in which some adjacent plagioclase crystals have about the same

[1]) The word metablast is used here in accordance with the definition of Dietrich and Mehnert (1960). A justification of de denomination of the minerals under discussion as metablasts will be given in chapter IX.

[2]) Mehnert (1957) did not encounter this type of quartz in his metablasts. He called "Tropfenquarze" what are named quartz crystals or grains in this paper.

crystallographic orientation. With this in view it is not strange that some rocks macroscopically classified in group *3*, appeared under the microscope to belong to group *1a*. The quartz comparator is often indispensable in showing the positions of the metablasts.

Sample 264 is a fine-grained variety, grey coloured with oval "eyelets" (length 1–2 mm) which are visible only because biotites occur in somewhat greater amounts around than within them. Some narrow bands in the sample are a little richer in biotite and therefore darker-coloured. Schistosity is hardly visible in the specimen.
In thin section the most conspicuous elements are quartz and orange-brown [1]) biotite, both with sizes around .5 mm. The biotite is present in rather thick crystals that do not show a preferred orientation. The quartz crystals are locally somewhat elongated. In addition, numerous thin biotite flakes (length < .2 mm) lie parallel with the direction indicated by the longer axes of the elongated quartz crystals. They are enclosed within plagioclase metablasts together with mostly equidimensional quartz crystals (also < .2 mm) and droplets of quartz

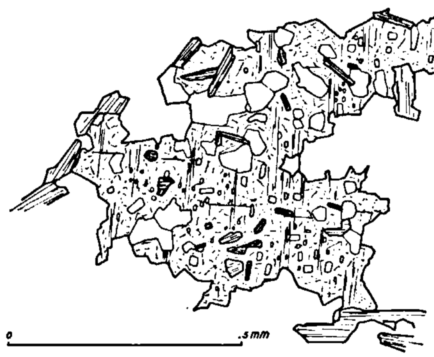


Fig. 38 Plagioclase metablast in paragneiss, group 1a, enclosing quartz crystals, droplets and biotite (264).

(< .025 mm) (fig. 38). The metablasts are so full of inclusions that their outlines are only well visible when using the quartz comparator. They are mostly smaller than 1 mm and several individuals together fill the spaces that appear in the specimen as "eyelets". Their composition is that of acid oligoclase, measured An values vary between 13 % and 16 %. Polysynthetic (010) twinning is common, lamellar (001) twins are less frequent. The quartz droplets have irregular, circular, oval, square or rectangular shapes. In one metablast several groups may be present having simultaneous extinctions within them but different extinctions when compared with each other. Spatially, droplets belonging to different groups may occur completely mixed. The exact reason of their occurrence (in nearly all metablast-bearing paragneisses) is not well understood. They are tentatively considered as reaction products rather than as small crystals that were enclosed by the growing metablasts. Muscovite is a minor constituent in this sample. It occurs unoriented, associated with the larger biotites and as thin flakes in the plagioclases (oriented parallel with the small biotites). The mineral has been observed to be enclosed by biotite. Between the metablasts some irregular interstitial microcline is present. Accessory minerals are zircon (rounded grains, mostly < .05 mm), apatite and some ore.

In the specimen of a coarser member of this group (204) grey "eyes" of between 2 and 4 mm are surrounded by narrow rims of biotite. The quantities of biotite are not constant throughout the rock. The quality of the reflections from cleavage planes of the plagioclases suggests that the latter are again studded with inclusions. A weakly planar texture is visible (fig. 40 a).

[1]) Unless stated otherwise, the colour of biotite described in this chapter is that of β and γ as observed in thin section.

Under the microscope the oval plagioclase metablasts are indeed observed to enclose many quartz crystals (lengths between .05 and .4 mm). Unlike the case described in 264 they are elongate and oriented with their long axes parallel with each other and also parallel with the long axes of most of their hosts. Both isolated crystals and continuous "trains" of inclusions were observed (fig. 39). Quartz droplets (< .04 mm) have not been noticed in all metablasts. Where present, they have properties as outlined in the description of the previous sample. Biotite is enclosed in relatively small amount; the narrow flakes range upwards in length to .35 mm and show an ill-pronounced orientation parallel with that of the quartz crystals. Garnet is not rare in the rock under discussion. The mineral has a maximum size of .35 mm but most crystals are around .1 mm. They are turbid; in some cases the cores are clearer than the rims (fig. 39). Part of the garnets has idiomorphic outlines; another part seems resorbed and has very irregular outlines but alteration products were never found: the mineral is always surrounded by plagioclase.

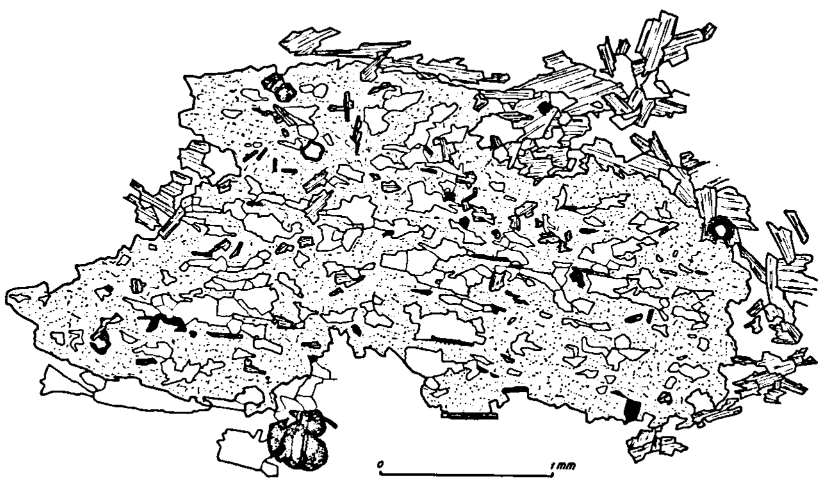


Fig. 39 Plagioclase metablast in paragneiss, group 1b, with enclosed quartz crystals, often arranged in "trains", biotite, garnet, apatite and ore (204).

Anorthite percentages between 27 % and 33 % have been measured in the metablasts. Cleavage traces are not well developed. Polysynthetic twinning on (001) is more common than on (010). The crystals reach sizes of 5 mm. Clouds of carbonaceous matter are locally present within them.
The macroscopically observed biotite concentrations around the metablasts contain (besides biotite) quartz and some plagioclase. The biotite shows neither a preferential orientation nor bent crystals; it forms thicker flakes than the biotite elsewhere in the rock and has a maximum length of .5mm. Also present outside the metablasts are a few more or less continuous and wavy "trains" of quartz crystals, parallel with the quartz in the plagioclases. Finally some seams with about equal amounts of fine-grained (< .2 mm) plagioclase and quartz and even smaller flakes of biotite (oriented parallel with the quartz crystals and trains) have been observed around the metablasts, especially where no concentrations of coarse biotite are present. All biotite has an orange-brown colour. Alteration into chlorite is rare. Apatite, rounded zircon (< .08 mm) and ore are accessory minerals.

1b. Paragneisses with considerable quantities of quartz and mica around plagioclase metablasts with enclosed quartz droplets and crystals

A gradual transition exists between the rocks of this group and those of the previous one. A complete and detailed description of all varieties as observed in thin sections is therefore superfluous. All but two gneisses with metablasts exceeding 3 mm in length and many with

plagioclase "eyelets" between 1 and 3 mm have to be placed in this group, whereas rocks without macroscopically recognizable metablasts are absent. More gneisses with metablasts enclosing elongated quartz crystals that have a direction not parallel with the schistosity of the rock fall within this group than within group *1a*. In most cases it seems more likely to suppose that the direction of the enclosed quartz grains reflects an older, helycitic fabric than that their plagioclase hosts have been rotated.
Muscovite is present outside the metablasts in varying amounts together with biotite. The mineral shows a stronger tendency to be oriented parallel with the schistosity of the rock than does biotite. The latter mineral is present as unoriented flakes, as crystals with outlines but no optical directions parallel with the schistosity and also as flakes that are crystallographically parallel with the schistosity. Quartz and biotite around the metablasts always are of coarser grain than the same minerals enclosed within them.

Two samples were selected for description, one with equidimensional quartz crystals enclosed in the metablasts (396), the other with elongated quartz inclusions (489). The

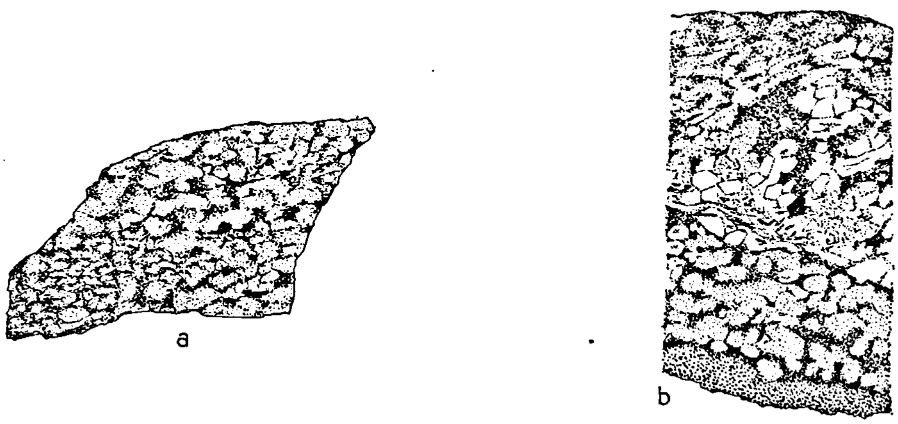


Fig. 40 Metablastic plagioclase-bearing paragneisses. a: group 1a (204); b: group 1b (396). Natural size.

first rock differs from those described in the preceding group in that it contains plagioclases up to 6 mm in size and irregular masses of coarse quartz. The second exemplifies a type with elongated quartz inclusions oblique to the schitosity of the rock.

In specimen 396 oval plagioclases mostly between 4 and 6 mm long with numerous tiny biotite inclusions are clearly visible. They do not have cleavage planes that reflect the light. These metablasts are embedded in fine-grained (< .5 mm) masses of biotite and light-coloured minerals. Some zones contain coarser elongated biotite flakes (1–2 mm) with a conspicuous preferred orientation. They are the only indicators of schistosity in the samples that as a whole have a massive aspect. Discontinuous, irregular bands of quartz up to 8 mm wide are found locally between the above-mentioned components (fig. 40 b).
Under the microscope these quartz bands appear to contain a little metablastic plagioclase in narrow seams. The plagioclase encloses small quartz crystals, biotite and muscovite and has uniform extinction sometimes over a considerable area around larger quartz crystals (fig. 41). The quartz of the bands shows a weak preferential orientation when observed with the quartz comparator. The undulose crystals are large: one measures 5 × 1.5 mm, others are less elongate and not longer than 4 mm. The macroscopically visible oval plagioclases enclose much quartz of varying size: crystals belonging to the quartz bands mentioned above, smaller equidimensional crystals between .1 and .3 mm and droplets of quartz (in this specimen in small amounts and not exceeding .07 mm). Narrow biotite flakes with maximum lengths of about .3 mm and a not very conspicuous preferred orientation parallel to that of coarser biotites outside the metablasts and some small muscovite flakes are also enclosed. It was diffi-

cult to determine the anorthite content of the plagioclases since cleavage traces are often invisible, irregular cracks filled with a low-refringent alteration product occurring instead. Percentages between 20 % and 27 % have been measured. In some cases crystals do not show uniform extinction due to slight differences in An-content. Twinning is not common. The observed twins on (010) and (001) are polysynthetic.

The fine-grained masses around the metablasts appear to consist of biotite, quartz, plagioclase and some muscovite. Biotite is present as rather thick crystals in contrast with muscovite that forms thin crystals. The biotite of these masses and of some coarser aggregates consisting of this mineral alone shows preferential orientation indicative of the schistosity, in the former less pronounced than in the latter. Locally, only a few quartz crystals surround metablasts.

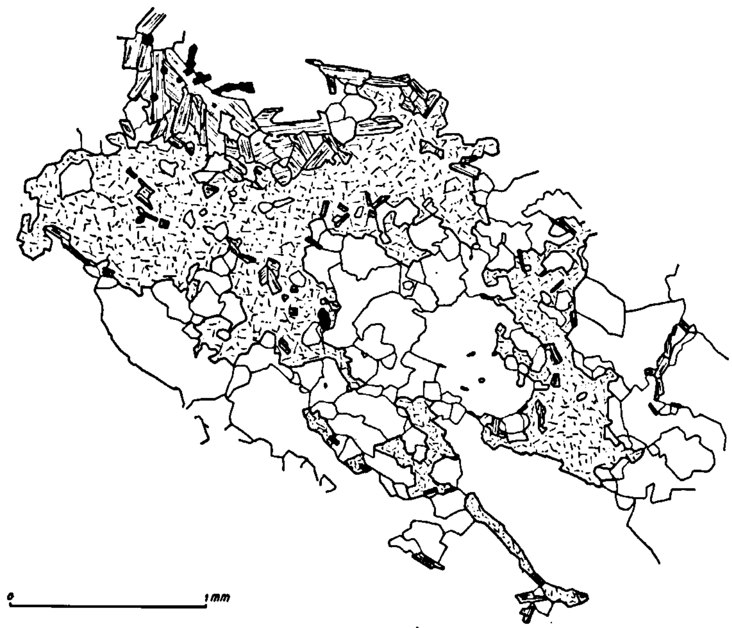


Fig. 41 Plagioclase metablast in paragneiss, group 1b, with enclosed quartz, mica and ore (396).

All biotite in the thin section has an orange-brown colour; the mineral is only rarely altered into chlorite. As accessories zircon (rounded crystals up to .12 mm) and ore have been noticed.

In contrast with the previous sample, 489 clearly shows a planar fabric: muscovite and some biotite are concentrated on schistosity planes that separate bands with predominantly lens-shaped and in a few cases round plagioclase metablasts (2–3 mm). Some plagioclase cleavages reflect light. Straight quartz bands with a maximum thickness of 1.5 mm are also visible in the specimen.

In the thin section an anorthite content between 17 % and 26 % has been measured in the plagioclase. The extinction of some crystals is not uniform because of a varying anorthite percentage. Polysynthetic (010) and (001) twins are visible in some individuals. Most metablasts enclose countless tiny quartz droplets (.01–.03 mm). It is not uncommon that nearly all droplets in one metablast have the same optical orientation. In addition, elongated quartz crystals up to .7 mm but mostly between .4 and .1 mm have been observed enclosed within metablastic plagioclase. The directions of these quartz inclusions and of thin biotite flakes (.1–.3 mm long) lying parallel with them probably depict an old metablastically overprinted fabric: more or less disregarding boundaries of individual metablasts and the macroscopically

visible schistosity, the pattern of inclusions suggests a microfolded fabric. Similar observations on another sample will be described in more detail in chapter VIII.
Quartz and biotite (lengths around .3 mm) are locally found between metablasts. As remarked already, layers of predominantly plagioclase alternate with a few bands consisting of quartz (.5–2 mm) and some thin flakes of muscovite and with micaceous layers that cause the schistose aspect of the rock. Muscovite (length max. 1.5 mm) is present in these layers in larger amount than biotite (up to 1 mm), while the former mineral also has a more pronounced preferred orientation. Both minerals have been observed to enclose each other. The colour of all biotite in the section is reddish brown, alteration into chlorite is rare. Accessory minerals are apatite, rounded zircons (not exceeding .06 mm), opaque minerals, a few rutiles and some carbonaceous matter.

2. Gneisses with quartz droplets but only a few quartz crystals enclosed within plagioclase metablasts

Macroscopically rocks of this group are not distinguishable from those of group *1b*. Occasionally the plagioclase cleavages reflect light better than in the preceding group because they are less speckled with quartz inclusions. In thin section it became clear that quartz needs not necessarily be a rare component of the whole rock. The mineral occurs concentrated in bands or zones and not regularly dispersed. Thin sections of samples with a banded structure demonstrate this very clearly.

In the specimen selected for description (506) a banded structure does not find expression on the raw surfaces but on the saw cut a band somewhat richer in biotite is weakly visible. The rock is schistose with muscovite and subordinate biotite concentrated on wavy surfaces around oval plagioclase metablasts (up to 5 mm) which have their long axes parallel with the schistosity and enclose much relatively coarse biotite. Outside the metablasts biotite flakes with an orientation perpendicular to the plane of schistosity are not rare ("cross-biotites"). They have a parallel arrangement that causes the superposition of a linear component upon the schistose fabric. A few lenses of quartz reach a width of 5 mm.
Study of the thin section clearly reveals that the rock has a banded structure: two bands with much quartz both in and around metablasts (type *1b*) and one other in between containing only a few quartz crystals enclosed within, and also little quartz in the spaces between metablasts. Quartz droplets are profusely present in plagioclases of both bands. The transitions between the bands are formed by quartz laminae with generally equidimensional crystals often longer than 1 mm (maximum 6.5 mm). The thickness of these laminae does not exceed 3 mm. Only the band belonging to the group under discussion will be described next.
The metablasts have an anorthite content between 15 % and 18 %. In a few crystals more basic patches (up to 32 %) have been found, one other patch has an albitic composition (3 % An). Twins are lamellar on (010) and (001) but not common. Quartz, biotite and some muscovite are the enclosed minerals. Quartz is mainly present as small droplets (.02–.04 mm) with all the properties that have been described in 264 and 489. Per definition the amount of enclosed quartz crystals (equidimensional, .1–.3 mm) is small. If present they are sometimes arranged in "trains". Biotite inclusions, on the other hand, are more numerous than in the previous samples. Their length varies between .1 and .3 mm and they often have parallel orientations. Muscovite displays the same characteristics: the flakes are thinner than those of biotite.
Around the metablasts the band is mainly composed of muscovite and biotite with in some portions a few plagioclases or quartz crystals of about the same dimensions as the micas. Muscovite shows more orientation parallel to the schistosity plane than does biotite that might even possess a weak preferential orientation perpendicular to the schistosity. Both micas measure 1 mm or less and enclose each other. Muscovite crystals are thinner than biotites; the latter are not rarely "thicker" than they are "long!" All biotite has a red-brown colour. Rounded zircons (< .06 mm), apatite and small grains of opaque mineral are the accessories.

3. Paragneisses with only a few or without plagioclase metablasts

The gneisses of the third group owe the scarcity or absence of plagioclase metablasts to many causes that are not related with each other. Various types will be distinguished in the following paragraphs, but a detailed description of specimens is not always considered necessary since some rocktypes in the group are rare, while others will be described fully in later sections of this chapter.

Rocks of group *3* have mainly been found in limited parts of the investigated area. In the southwest, they occur among rocks allotted to groups *1* and *2* near contacts with two-mica granites. They have also been found on and west of the ridge Las Pereiras, NE of Zamanes. The majority of the samples of this group, however, derives from the northeastern part of the region, where it turns out that all specimens collected in outcrops of paragneiss surrounded by orthogneiss, in the paragneissband between the main orthogneiss body and the "Lonsa dome", and immediately east and south of the latter have either macroscopically indistinguishable plagioclase metablasts or eyelets smaller than 1 mm.

Micaschists constitute a *first type* in group *3*. Only threes amples have been collected: two (49 and 150) in the southwestern part of the area where paragneisses with coarse metablasts (see group *1b*, sample 396) predominate and one (316) in a sharp turn of the road Zamanes-Porriño, near Cela. Southwest of Cela, micaschist in a very weathered state has often been noticed. The fresh specimen 316 is very rich in muscovite. Biotite is less conspicuous; a few tourmaline prisms lie with their long axes in the schistosity plane.
In thin section quartz, muscovite, biotite, tourmaline, zircon and ore have been noted. Quartz is present as grains with varying size, undulose extinction and irregular outlines. It is arranged in wavy bands that are often interrupted by mica. Part of the muscovite lies parallel with the quartz bands in the schistosity plane, the rest is seemingly oriented at random. Biotite does not seem to be preferentially oriented either. Both minerals have irregular outlines and are often enclosing each other. The sizes of quartz, muscovite and biotite do not exceed 1 mm. Tourmaline reaches a length of 1.5 mm; the crystals are xenomorphic and mostly poeciloblastic. The colour of ω is lightbrown in outer parts and olive green in interior parts. One rounded zircon of .1 mm long has been observed, many others are much smaller and also rounded.

The two samples collected in the southwestern part of the area have only a high apatite content in common. One, a garnet-micaschist (49), has been found as a loose fragment. Despite much searching, no other piece of the same rock could be found. Since it has been come across in a lonely place, it is improbable that it has been dropped by human hand. The specimen is very schistose. Muscovite is the main constituent, biotite nearly absent in some parts; a few thin bands of quartz are visible. In this matrix many idiomorphic red garnets, mostly between 5 and 10 mm are set. In thin section they are very fresh (in contrast with the garnets in nearly all other paragneisses of the area that are smaller, turbid and often seem resorbed). They enclose a few crystals of apatite and quartz. A great part of the surrounding muscovite (length up to 3.5 mm) is oriented in the schistosity plane but unoriented muscovite is not rare. Biotite, not longer than 2 mm, present in subordinate amount in one half and nearly absent in the other half of the section shows the same disposition. Apatite is so frequent that the mineral is a minor and not an accessory constituent. It reaches a length of 1 mm. Only a few quartz crystals were recorded outside the garnets, since the quartz bands in the specimen were not cut by the thin section. As accessories small rounded zircons, monazite grains and carbonaceous matter have been observed.

The other sample (150) is a chlorite schist. Quartz is more common than in 49, forms thick, irregular bands of inequigranular, undulose grains (up to 5 mm) with indented boundaries and encloses some muscovite, chlorite, apatite and biotite. The remainder of the slide is composed of chlorite, oriented more or less parallel with the outlines of the bands in which it occurs. It encloses leucoxene, opaque mineral and sagenite and has parallel intergrowths with muscovite. The quantities of apatite (up to 2 mm) are larger in these parts than in the quartz bands. Criss-cross in the rock lie lepidoblasts of muscovite, longer in the chlorite portions (1–2 mm) than in the quartz ($<$ .6 mm). Few and small rounded zircons occur as accessories together with the ore and leucoxene already mentioned.

Some gneisses near the contacts with two-mica granite in the SW of the area belong to a *second type* of group *3*. Metablasts are often absent and the rocks instead are constituted of granular mosaics of quartz, plagioclase and rather coarse mica (grainsize of all minerals around 1 mm). In some cases *lit-par-lit* injection of granitic material has taken place. It should be remarked, however, that rocks with granular mosaics have also been found elsewhere in the investigated region, where granite is not cropping out in the neighbourhood. In these cases the mosaics are more regular and of finer grain (about .3 mm).

In the first paragraph of the description of group *1a* it has been stated that some extremely fine-grained gneisses do not show plagioclase metablasts but mosaics of quartz and plagioclase. Because the subdivision adopted here is based upon the presence or absence of metablasts these gneisses have to be mentioned here as a *third type* of group *3*. Instead of plagioclase metablasts with quartz inclusions of about .1 mm a typical example of gneiss with very fine grains has a granular mosaic of quartz, plagioclase and biotite, all around .1 mm. In various cases adjacent plagioclases have about parallel crystallographical orientations in groups. The biotite does not show a conspicuous preferred orientation. Embedded in this mosaic lie quartz grains with sizes that often reach .3 mm. Some rocks of the following type possess similar properties; they are nevertheless treated separately because they all display some other characteristics absent in the rocks of this type.

The paragneisses cropping out in the vicinity of orthogneiss will be considered as a *fourth type* of group 3, though they actually differ so much between themselves that this lumping is not very elegant. For information regarding their distribution the reader is referred to the introductory paragraph of this group. Nine specimens were classed in group *1a*, five of them have macroscopically recognizable eyelets smaller than 1 mm. Eleven samples belong to this type proper because they do not exhibit plagioclase metablasts. In ten slides the occurrence of one or more of the minerals cordierite, andalusite or sillimanite has been recorded. A description of these rocks will be given below under the heading "Lonsa-type paragneisses".

A few remarks on the rocks found on and around Las Pereiras (together constituting the *fifth type*) are sufficient. Most of the samples collected in that part of the area are rich in cordierite. In some, plagioclase metablasts are visible with the unaided eye, whereas in others they only appear under the microscope. They should have to be classified into groups *1b*, *2* and *3*. The fact that they all contain cordierite is more important in the opinion of the author; he will therefore describe them together as cordierite gneisses of the "Pereiras-type" in a subsequent section.

Special types of paragneiss

Cummingtonite-biotite-garnet-bearing quartz-bytownite rock

When the new highway from Puxeiros to Vigo was being constructed, the author had a good opportunity to collect some samples from an important road cut in fresh paragneiss about 800 m from the Plaza de España in Vigo. One of the specimens (771A) has a part with a bluish to greenish grey colour, different from the grey colour of the rest of the rock. In a thin section, cut through both normally and abnormally coloured parts, it could be seen that the two have very different mineralogical compositions and that a transitional zone, .5 to 1.5 cm wide exists in between.

The normal zone consists of metablastic paragneiss, group *1b*. The abnormally coloured zone is metablastic too, but without much quartz around the metablasts. The composition of the plagioclase is very different. In the normal zone it is that of acid to intermediate andesine, whereas in the zone under discussion it is bytownite, very similar to the plagioclases in some amphibolitic rocks (chapter V; samples 87, 392, 395, 402, 508A; fig. 29). The metablasts have sizes varying between .5 and 2 mm, the quartz crystals enclosed within them range from .04 to .2 mm, i.e., they are more variable and coarser in grain than the quartz enclosed within the amphibolites mentioned above which are around .05 mm. Between the metablasts some undulose quartz of .3–.5 mm is present. The shape of the smaller quartz inclusions is often remarkably circular; the larger ones are more irregular. Like the bytownites in the amphibolites, the plagioclases of the rock part under discussion are mostly untwinned; when present twins are polysynthetic on (010) and (001) with narrow lamellae or rare Carlsbad twins. Alteration into muscovite with crystallographically determined directions is common. A great number of garnets lies embedded in the bytownite. They are smaller than .1 mm, idiomorphic and less turbid than garnets in the normal paragneisses often are. In a few crystals quartz or opaque mineral is enclosed. Rust-brown biotite flakes (up to .5 mm), somewhat altered into chlorite, are also more frequently surrounded by plagioclase than by quartz. The third minor constituent is cummingtonitic amphibole. In all respects this amphibole equals that in the amphibolitic rocks. The crystals range upwards to .3 mm, alter into chlorite and are found in quartz and in bytownite. Accessory minerals are apatite, titanite, zircon (xenomorphic or rounded grains, max. length .1 mm) and opaque minerals (more common than in the paragneiss of the normal part of the specimen).

The transitional zone signalized in the first paragraph of this section is mainly composed of quartz (length up to 3 mm). Plagioclase, biotite, apatite and opaque mineral occur in between. The anorthite content of the plagioclase decreases in the direction of the normal gneiss as could be deduced from the relief of the mineral. In the normal gneiss a preferred orientation of small biotites has been observed making an angle of about 45° with the boundaries between the normal and abnormal zones. In the transitional zone this direction is roughly reflected by irregular bands of quartz and intercalated bands with plagioclase, whereas in the bytownite-bearing rock no preferred orientation or any alignment of minerals is visible.

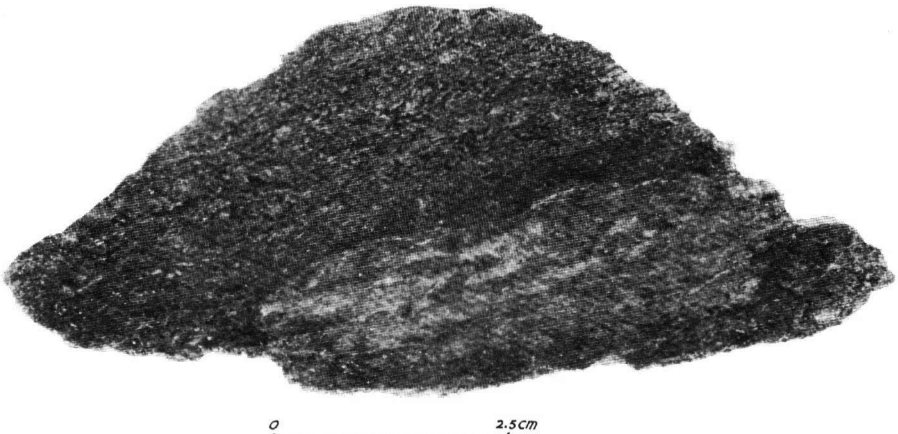


Fig. 42 Cordierite nodule (lighter-coloured) in Pereiras-type paragneiss (398).

Cordierite gneisses of Las Pereiras

Large rounded paragneiss-blocks lie surrounded by vegetation on the ridge of Las Pereiras, on its eastern and western slopes, and on the junction with the southern slope of Pedra Cavalaria, W of Las Pereiras. Most specimens collected in this area either contain bluish grey oval cordierite nodules, not exceeding 5 cm in length (fig. 42), or cordierite dispersed among the other composing minerals. The rocks are schistose and rich in muscovite and biotite; the former mineral lies with its basal cleavage in the schistosity plane, the latter does not show a preferred orientation. As remarked above, plagioclases are often visible with the unaided eye; in most cases it is impossible to ascertain whether they occur as metablasts or as fine grains since conspicuous eyelets are mostly lacking. Microfolds are not rare but it is not sure that the blocks that show them indeed retained their original positions. Cordierite nodules offer more resistance to weathering than does the rest of the gneiss. It is therefore quite well possible that the unexposed rock around the blocks is actually devoid of cordierite and that the impression one has that the area is completely underlain by cordierite gneiss is wrong. Similar gneisses without cordierite nodules but with cordierite as a minor constituent have been found in several isolated localities elsewhere in the region and also SE of the mapped area along the road Paramós-Salceda.

The specimen selected for description (398) displays the properties outlined above. Plagioclase metablasts are not visible macroscopically. A thin section has been made cutting both cordierite nodule and surrounding gneiss.

In the cordierite-bearing part quartz bands in recumbent microfolds consisting of elongated crystals up to 1.5 mm have been metablastically [1]) enclosed by cordierite and some plagio-

[1]) See note, p. 117.

clase. The cordierites are xenomorphic, often elongated parallel to the schistosity, irregularly intergrown both with each other and with plagioclase and have a length up to 3 mm. Nearly all cordierites have subparallel extinction positions as could be seen with the quartz comparator. The mineral encloses quartz ranging in size from droplets comparable with those in plagioclase to crystals of nearly 1 mm, is unaltered and in a few cases exhibits polysynthetic twins; dark yellow pleochroic haloes are present around radioactive inclusions. Plagioclase is metablastic with enclosed quartz crystals and droplets. Muscovite is more common in cordierite than in plagioclase. The flakes have a maximum length of 1 mm, parallel orientations and follow the microfolded structure. Biotite is rare, altered into chlorite and smaller than

Fig. 43 Cordierite (dotted) enclosing several plagioclase fragments with orientations identical to that of a plagioclase adjacent to cordierite (bottom). Note small rounded biotite in cordierite. Pereiras-type cordierite gneiss (404).

muscovite. It also seems to be somewhat resorbed and to follow the microfolds. Bent crystals of muscovite and biotite were not observed. Grains of opaque mineral up to .5 mm are much more common within the cordierite nodule than around it. In a polished section the following minerals have been determined by Dr. P. J. M. Ypma: ilmenite with extremely fine exsolution lamellae of hematite, pyrrhotite with some chalcopyrite, pyrite. Apatite, zircon, monazite (?) and one small resorbed relic of garnet have been noted as accessories.

The gneissic counterpart of the cordierite nodule distinguishes itself (apart from the absence of cordierite) mainly by the relative abundance of coarse (up to 1.3 mm) and thick, unoriented biotite flakes. Their colour is greenish brown, whereas biotite in the cordierite has a rust-brown colour. The study of thin sections of other specimens, however, showed this difference to be only accidental. Alteration into chlorite is less frequent than in the nodule. Muscovite, parallel with the schistosity, reaches 2 mm length, but is mostly smaller than 1 mm; it encloses small flakes of biotite in parallel intergrowth. Muscovite in biotite has been noted as well. Quartz bands are also present in this part of the rock. The elongated crystals are smaller (1 mm max.) and the bands thinner, while microfolds have not been noticed. Plagioclase metablasts are more or less hidden between the coarse micas. They are often elongate (length up to 3 mm) and enclose quartz droplets and elongated quartz crystals in some bands of the slide; other zones contain metablasts without quartz crystals or with a few equidimensional grains. Tiny flakes of biotite and muscovite arranged parallel with the schistosity lie embedded in metablastic plagioclase. Locally, fine-grained masses of plagioclase and quartz (smaller than .3 mm) have been observed. The anorthite-content of the plagioclase varies between 20 % and 25 %. A patchy distribution of areas with slightly different compositions has been noticed in some metablasts, whereas some crystals in the fine-grained portions are zoned, the core being a little more basic. Tiny prisms of tourmaline and two larger hypidiomorphic crystals have a pleochroism from blue-green to pinkish brown. Like the nodule, this part of the thin section contains one resorbed garnet .07 mm across. Accessories are apatite, zircon, a radioactive mineral that causes very large pleochroic haloes in biotite (monazite?) and opaque ore.

Other thin sections do not show essential differences from the picture sketched above. The quantities of cordierite vary: some slides consist almost exclusively of the mineral, whereas in others it is only a minor constituent occurring among the other minerals of the rock. Biotite enclosed by cordierite often shows rounded outlines. The quartz content is also variable. In one specimen (416), for instance, quartz crystals are scarce, whereas in another (417), collected at short distance from 416, quartz is common but irregularly distributed: In the upper part of the thin section of 417 rather small cordierites are present between bands of elongated quartz. Next to this, similar bands of quartz are observed to be metablastically enclosed by cordierite and some plagioclase. In a third zone large plagioclase metablasts do not contain many enclosed quartz crystals; in the surrounding aggregates mica is more

TABLE 18 *Chemical composition of paragneiss and greywacke (weight percent)*

	1	2	3	4
SiO_2	64.04	65.89	67.21	64.7
Al_2O_3	16.87	16.68	15.46	14.8
Fe_2O_3	3.15	1.38	2.11	1.5
FeO	3.16	3.34	3.41	3.9
MnO	.11	.06	.07	.1
MgO	2.47	1.86	1.69	2.2
CaO	2.04	2.80	1.93	3.1
Na_2O	3.28	3.55	3.19	3.1
K_2O	2.15	2.58	2.97	1.9
H_2O	1.32	.95	1.11	3.1
TiO_2	.75	.93	.73	.5
P_2O_5	.23	—	.12	.2
SO_3				.4
CO_2				1.3
S				.2
	99.57	100.02	100.00	101.0

1. Andalusite- and muscovite-bearing cordierite-plagioclase paragneiss, 423, Las Pereiras, Vigo, Spain. Analyst: Mrs. H. M. I. Bult-Bik.
2. Average intermediate schistose paragneiss, Black Forest, Germany. (Mehnert, 1953).
3. Average paragneiss, Black Forest. Germany. (Mehnert, 1953).
4. Average greywacke (Pettijohn, 1957).

common than quartz. A last part is equal to the second one described above. All cordierites and plagioclases in this part have subparallel extinctions when inspected with the quartz comparator.

Green-brown biotite is more common in rocks of Las Pereiras than in any other rock in the area. Tourmaline has a blue-to bottle-green colour in rocks with this biotite; in gneisses with rust-brown biotite the tourmaline has brownish tinges. Garnet is usually more common than in the described specimen 398. It is always present as partially resorbed, turbid crystals. Incipient blastesis of albite in metablastic oligoclase is not uncommon. A few xenomorphic grains of andalusite have been recorded in 416, one hypidiomorphic crystal in 423. In many thin sections tiny sheaf-like aggregates of a mineral that is supposed to be sillimanite are present along grain boundaries. The needles are so thin (< .005 mm) that it is impossible to determine their optical properties.

A phenomenon that has been observed only once is illustrated in fig. 43. A cordierite crystal encloses several patches of plagioclase with irregularly curved outlines. The orientations of these patches and of a plagioclase adjacent to the cordierite that contains the patches are strictly parallel. The intergrowth suggests that cordierite grew at the expense of plagioclase.

One chemical analysis of cordierite gneiss (specimen 423) is given in table 18. The rock resembles 398 but the minerals are less regularly distributed. The maximum lengths of the metablasts is 4.5 mm. One hypidiomorphic andalusite (1 mm across) has grown around and at the expense of unoriented biotite.

Paragneisses with andalusite or sillimanite

Only four thin sections have been made that proved to contain a few crystals of andalusite and no sillimanite or cordierite. They were collected at widely separated localities: one in the extreme SE of the map area, one among the coarsely metablastic gneisses W of the Sierra de Galiñeiro and the remaining two in the city of Vigo but also wide apart. One specimen has been alloted to group *1a*, two to group *1b* and one to group *2* after the properties of their plagioclases. Sample 602, collected at the northern entrance of the new railway tunnel traversing the peninsula of La Guia is the only specimen that contains a hypidiomorphic crystal of andalusite. The other crystals in that sample and also in the three others are xenomorphic. All crystals are poeciloblastic and enclose one or more of the minerals quartz, biotite, muscovite, garnet, zircon, apatite and ore. The length of the largest andalusite found is 3 mm.

Gneisses with sillimanite but without andalusite or cordierite occur in the extreme SW of the western paragneiss zone near coarse-grained two-mica granites. In three thin sections the mineral has been observed. One was collected in an outcrop only a few metres from the coarse-grained inequigranular two-mica granite and contains rather thick masses of sillimanite embedded in muscovite, biotite and quartz. In the two other samples sparse needles lie enclosed within muscovite. The muscovites of all three specimens are thick crystals of random orientation; they belong to the muscovite lepidoblasts to be described below. Small groups of tiny needles of probable sillimanite have been found along grain boundaries in many specimens. They have not been taken into consideration here.

Lonsa-type paragneisses (including sillimanite-andalusite-cordierite gneiss)

In the section dealing with group *3* the gneisses to be described here have been briefly mentioned twice: in the introduction and as a fourth type. It is possible to divide the 20 specimens collected into four sub-types: A, the nine specimens belonging to group *1a*; B, four samples with granoblastic quartz-plagioclase mosaics; C, three rocks with much elongated quartz and with small plagioclases not enclosing quartz crystals or droplets; D, four specimens containing plagioclases of varying grainsize (also some metablasts).

Cordierite is generally not present as large crystals (the normal habit in the gneisses of Las Pereiras) but as aggregates of small, often altered grains. They have been observed in four specimens (in sub-types A and B) and in two cordierite-bearing gneisses with metablasts up to 3 mm (807, group *1a*) and 1 mm (597, group *1a*), collected near the western contact of the main orthogneiss body, S of Bembribe and N of Lavadores respectively. They are the only cordierite-bearing gneisses with the texture characteristic of Lonsa-type cordierite gneisses occurring outside the area delimited in the introductory paragraph of group *3*. Important in 807 is the occurrence of cordierite within a plagioclase metablast. Other cordierite aggregates are always arranged between the metablasts.

Four rocks of sub-type A are banded. One of them (804) will be described in detail. The unbanded ones resemble the fine-grained varieties in group *1a*. Specimen 804 is inconspicuously banded, planar, with plagioclase metablasts visible in one band only. The colour is light grey.

In thin section seven successive bands could be distinguished:

Band 1, thickness 6 mm, is a fine-grained metablastic biotite gneiss with garnets (up to .4 mm) and a few grains of altered cordierite. It is very rich in quartz (smaller than .5 mm), the crystals of which are elongated parallel to the banding and lie among the plagioclase metablasts. The latter enclose mostly equidimensional quartz crystals and droplets and are smaller than 1 mm, mostly even smaller than .7 mm. Biotite is also fine-grained (< .15 mm) and largely oriented parallel with the banding of the rock.

Band 2, thickness 2 mm. This zone is characterized by a few continuous bands of mostly equidimensional quartz grains (max. length 1.5 mm). Between the quartz bands lie lenses or irregularly branching aggregates of fine-grained altered cordierite (< .5 mm), plagioclase, biotite and garnet (.5 mm). Biotite flakes have been observed parallel with the bands, but also as coarser flakes oblique to this direction.

Band 3, thickness 7 mm, is quartz-poor, very inequigranular, without quartz seams or elongated crystals. It is composed of plagioclase metablasts (max. 2 mm, mostly smaller than 1.5 mm), cordierite in aggregates (grains < .1 mm) often with subparallel extinctions and also some larger crystals (max. .7 mm), unoriented biotite in thick flakes (length max. .5 mm), chlorite in thinner crystals than biotite, garnet (up to .5 mm) and one olive-green and brown tourmaline poeciloblast. The vast majority of the garnets is enclosed by plagioclase; a few have been found in cordierite aggregates, none in one of the larger cordierites. Actually three parallel parts can be distinguished in this band: a central zone that contains very little quartz, even in the large plagioclase metablasts, and two transitional zones with increasing quartz contents towards bands 2 and 4 reflected by more abundant equigranular quartz enclosed within the (smaller) plagioclase metablasts. In the transition to band 2 cordierite aggregates are present, whereas they are rare in the transition to band 4. A parallel orientation of minerals has not been observed.

Band 4, thickness 2–3 mm, is comparable with band 2 but contains less cordierite and more plagioclase: the quartz bands are interrupted by plagioclase. Also, the lenses of this mineral are less flat than in band 2. The equidimensional quartz grains range upwards to 1 mm. Of garnet only a few small grains have been noticed.

Band 5, thickness 5 mm, resembles band 3 without marginal zones. A quartz-rich lens is present in the middle of the band. Plagioclase metablasts with little enclosed quartz reach lengths up to 3.5 mm, cordierite is mainly present as aggregates of grains smaller than .1 mm but larger crystals (max. 1 mm) are not uncommon. In the cordierite aggregates small islets and poeciloblasts of andalusite with parallel extinctions in groups are of frequent occurrence, while one grain of a mineral resembling staurolite has also been observed. Garnet is rare. Opaque ore has amoeboid shapes.

Band 6, thickness 12 mm, is resembling band 1. It has coarser, somewhat elongated, quartz and finer plagioclase. Locally the fabric is more a mosaic of quartz and plagioclase, both about .4 mm across, while elsewhere the rock is metablastic with plagioclase up to 1 mm. Cordierite is more common than in band 1, aggregates of grains up to .2 mm lying dispersed throughout the whole band. Biotite has the same properties as in band 1. Only a few grains of garnet (< .1 mm) have been found.

Band 7, thickness 2 mm, is poorer in quartz than the previous band. The plagioclase metablasts are coarser (up to 2 mm) and enclose some equidimensional quartz grains. Around the metablasts there is not much quartz. Biotite is coarser than in band 6 (up to .3 mm) but hardly more abundant. Cordierite and garnet are present in the same way as in the preceding band.

In general, the plagioclases, whether small or large, do not show clear cleavage traces and determination of their anorthite contents is therefore rather difficult. Larger metablasts occasionally have a patchy distribution of parts with a somewhat different extinction angle,

smaller crystals often possess a higher refringent inner zone. The measured An-contents all vary within the range of oligoclase. Lamellar (010) and (001) twins have been observed. Cordierite is often altered into pinite or recognizable sericite.
Biotite has a rust-brown colour and is altered into chlorite. Small biotite flakes generally lie parallel with the banding. Thin but long chlorite flakes as observed in bands 3 and 5 cannot have originated by simple alteration of biotite since crystals of that mineral with such habits were never seen. Similar chlorites have been noticed in other Lonsa-type gneisses too. Garnet is always xenomorphic, turbid and resorbed, sometimes associated with biotite. Large (.5 mm) garnets are present only in bands 1, 2 and 3. Muscovite occurs only sporadically as alteration product of plagioclase. The accessories apatite, rounded zircon and opaque ore have been noted in all bands of the rock.

The thin section described above suggests that in specimen 804 original differences in quartz content played a big role in the determination of the texture in the various bands of the rock. The same has been observed in the other three banded specimens, in two of which cordierite, andalusite or sillimanite are lacking. The relatively quartz-poor bands contain larger plagioclase metablasts with enclosed equidimensional quartz grains and with more mica around them than the bands richer in quartz. These have elongated quartz grains besides smaller metablasts and less mica.

In the granoblastic quartz-plagioclase mosaics (grainsizes about .5 mm) of the rocks of sub-type B no preferred orientation of biotite or muscovite has been observed. One thin section, however, contains parallel small biotites in finer-grained aggregates, richer in mica, with small quartz and plagioclase grains surrounded by limonitic rims, while two slides show small parallel biotites in fine-grained aggregates with plagioclase, quartz, cordierite, sillimanite, and in one of the two andalusite. In the thin section carrying andalusite within the aggregates, the biotite-content of the same is lower than that of the surrounding quartz-plagioclase-mica mosaics. A few grains resembling corundum were also observed in the aggregates, the minerals of which show implication intergrowth. Some xenoliths in cordierite-quartzdiorite are very similar to these cordierite-rich aggregates.

The fourth specimen belonging to this sub-type has been found in the immediate vicinity of granite related with cordierite-quartzdiorite. It is possible to compare the texture of this rock with that of the second type of group *3*, comprising paragneisses found near two-mica granite in the SW of the area. In its thin section some microcline has been noticed.

One sample (801) of the three belonging to sub-type C with much elongated quartz either as continuous bands or dispersed throughout the rock and with small granular plagioclases in between, contains much more mica than the two others and moreover the only idiomorphic andalusite crystals found in the area. Their maximum length observed is 3.5 mm, the thickness does not exceed .4 mm. Another characteristic of these andalusites is that they have pink pleochroic cores with anomal interference colours, strong dispersion $r > v$ and a smaller optic axial angle than have their normal rims. In another specimen, with some altered cordierite aggregates, thin and thick flakes of muscovite, both with lengths of around .5 mm, have been noted. The former lie mainly parallel to the schistosity plane, the latter are unoriented muscovite lepidoblasts to be described below.

The specimens of sub-type D are mica-rich. Three contain rather large crystals of cordierite and andalusite, while varying amounts of acicular sillimanite were also noted. Plagioclase and quartz are present as mosaics of small grains and also as larger metablasts with enclosed quartz crystals. Lepidoblastic muscovite is common.

As an example a description is given of specimen 713, a dark bluish grey, compact rock found loose along a path. In thin section the irregular outlines of many crystals of quartz and plagioclase and of all andalusites and muscovite lepidoblasts present are characteristic. A weakly foliated texture is indicated by discontinuous parallel bands or lenses of partly elongated quartz crystals (.5–1.5 mm). In the bands small quantities of plagioclase, cordierite and mica were noted too. Around the quartz bands the rock is composed of plagioclase-rich parts and portions consisting predominantly of cordierite; it is not possible, however, to separate these parts completely.
The former contain plagioclase metablasts (enclosing quartz in droplets and in equidimensional crystals but also in very irregular, amoeboid individuals) and small plagioclase crystals

showing subparallel extinction in groups, as could be established with the quartz comparator. The maximum length of the metablasts is 2 mm, the small crystals mostly vary between .1 and .3 mm. The latter are zoned with acid andesine cores and intermediate oligoclase rims, the transition between cores and rims being abrupt; the metablasts consist of oligoclase and are generally more uniform than the small crystals. Because clear cleavage traces are mostly lacking, their anorthite content could not be well determined. Some metablasts show irregular compositional variations.

In the cordierite-rich parts biotite and muscovite are oriented more strictly parallel to the foliation than in the plagioclase-rich portions where only small biotites have parallel orientation, whereas the larger ones are unoriented and all muscovite present is lepidoblastic. The maximum length of the biotite within cordierite is smaller than elsewhere in the rock (.5 v. .8 mm). Cordierite itself reaches 2 mm and is nearly unaltered. Xenomorphic and poeciloblastic andalusite encloses biotite that lies subparallel with the external foliation, quartz and a few grains of garnet, which mineral is absent elsewhere in the rock. The rims of some andalusites are symplectitic, while sillimanite rims have developed locally. Andalusite is in contact with quartz, plagioclase and cordierite but the sillimanitic rims do not seem to be specifically related with one of these surrounding minerals. Fibrous masses of sillimanite have grown locally in biotite, muscovite, plagioclase and quartz. The normal accessory minerals apatite, zircon (small rounded grains) and opaque ore have been recorded.

Important conclusions can be drawn from observations made in rocks of the Lonsa-type. They will be discussed in chapter IX.

Albite-bearing paragneiss

Limpid albites with the same properties as those in biotite-amphibole rocks and gneisses (chapter IV) have also been found in many paragneisses allotted to groups *1a*, *1b* and *2*, especially in the southern half of the mapped area (fig. 22). Thin sections show the mineral to be present in varying amounts. When scarce, it occurs as fresh irregular patches, mostly devoid of enclosed minerals, within somewhat altered oligoclase metablasts with many inclusions (e.g., quartz crystals and droplets, biotite, garnet, accessories). Inclusions within albite, if present, are surrounded by narrow rims of oligoclase. With increasing amounts of albite the mineral seems to spread through the metablasts, still avoiding contact with enclosed minerals. A next stage is that in which albite is more common than oligoclase. The albite is clear and surrounds more or less altered relics of oligoclase with enclosed minerals. In rocks with extremely abundant albite development oligoclase is completely absent; albite is macroscopically visible in them because its cleavage planes reflect the light very well. The mineral is generally untwinned or with simple twins, after the albite, Carlsbad and albite-Carlsbad laws; twins on (010) with one or a few broad discontinuous lamellae are less common. Because of the disappearance of the original oligoclase metablasts it is very difficult to assign albite-rich paragneisses to the groups *1a*, *1b* and *2* distinguished earlier in this chapter. Albites completely free from inherited inclusions are more likely to develop in rocks without much quartz than in rocks in which oligoclase metablasts originally enclosed many quartz crystals. In many albites tiny idiomorphic and clear prisms of rutile and zircon have been observed, minerals which are lacking (at least with this habit) elsewhere in the rocks and altogether in rocks without albite.

Microcline in paragneiss

29 of the 178 gneisses of which thin sections were made contain microcline. Only three derive from the northern half of the map area: one has been collected as a xenolith in two-mica granite on the peninsula of La Guia, one in an outcrop of Lonsa-type paragneiss very near granite related with cordierite-quartzdiorite and surrounded by orthogneiss, while the third was found along the highway Vigo-Porriño, not far from the latter village. The microcline in the last specimen occurs in a narrow alteration zone where biotite altered into chlorite and plagioclase has been partly replaced by microcline.

Nearly all microcline-bearing paragneisses in the southern part of the region have been found in the vicinity of or within the alkaline gneiss arc. Two specimens at greater distances contain microcline as a replacement mineral in relation with the general alteration of the rocks into chlorite gneisses. Of the remaining samples the majority is very fine-grained (cf. 264, group *1a*) and occurs in a N–S trending zone from N of Zamanes to Filgueiras, S of the eastern riebeckite gneiss band. The microcline occurs in these rocks as small xenomorphic grains between the other minerals and easily escapes notice when present in small amount. In some cases it replaces plagioclase.

The ten remaining specimens all contain 1–3 mm long plagioclase metablasts, consisting of oligoclase with variable quantities of albite. Granoblastic mosaics of microcline (grainsize .2–.5 mm) surround the metablasts. Epitaxic intergrowths of microcline within metablastic plagioclase are common. Only in a few of these aggregates microcline is the predominant feldspar. The relations suggest that microcline is the replacing component. Three samples of this type have been found enclosed by riebeckite gneiss SW, S and SE of Monte Galiñeiro, the other seven were collected just outside riebeckite gneiss (fig. 53).

Lepidoblastic muscovite-bearing paragneiss

Booklets of muscovite, occasionally as thick as they are long (.5–1 mm), lie without a preferred orientation in many specimens. Their outlines are very ragged except at the sides where they are bounded by their (001) planes; there are, however, exceptions to this rule and lepidoblasts that actually consist of various irregular parts oriented crystallographically subparallel to each other are not rare (fig. 44). Parts having cleavage traces that make angles of

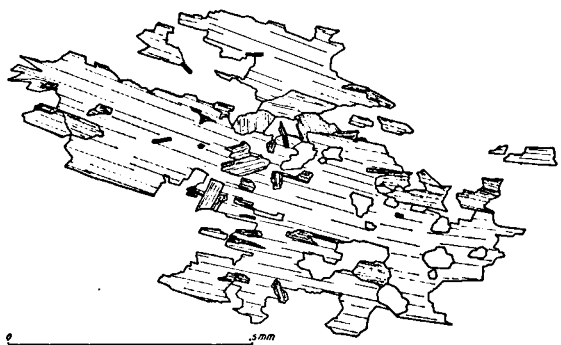


Fig. 44 Muscovite lepidoblast in paragneiss. Adjacent muscovite flakes are subparallel to the large crystal. Biotite is dotted (691C).

a few degrees with those of other parts were observed in several lepidoblasts (fig. 44). Probably these slight disorientations were caused by simultaneous blastic growth from various nuclei. Examples of such early stages are present in the thin sections investigated. The lepidoblasts are very similar to the muscovites in two-mica granites, cordierite-quartzdiorite and their related rocks (chapter II).

When the localities of the specimens that contain these muscovites are plotted on the geological map, it turns out that they all derive from regions where one of the granitic rocks mentioned above is nearby: They occur in the southwestern part of the map area in the vicinity of contacts with coarse-grained inequigranular, coarse-grained equigranular, and medium-grained inequigranular two-mica granites; on the peninsula of La Guia they have been found in xenoliths enclosed within the medium- to coarse-grained equigranular two-mica granite; finally, rocks with muscovite lepidoblasts are very common in the paragneiss bands within the area of distribution of the cordierite-quartzdiorite and related rocks (fig. 53). The lepidoblasts have been observed to enclose some biotite and in a few samples sillimanite needles, but more often they are inclusion-free.

Tourmaline-rich schists

For information regarding schists metasomatically enriched in tourmaline the reader is referred to the last section of chapter II, where mention of these rocks has already been made.

SUMMARY

The observations that may shed light on the genesis and history of the paragneisses will be briefly reviewed below. Remarks regarding the individual minerals precede those about the textures and distribution of the various gneisses.

Quartz, although constantly present, varies in amount. When relatively scarce it is found almost exclusively enclosed within metablastic plagioclase, either as tiny droplets with parallel extinction directions in groups or as larger crystals of equidimensional or elongate shape. With increasing quartz content the mineral will be found also outside the plagioclases as individual crystals larger than the enclosed ones ("Zwickelquarze" in the German nomenclature) and as bands. Fine-grained gneisses may contain separate crystals or thin, continuous "trains" of equidimensional or elongate crystals, whereas in coarse-grained varieties the quartz is usually present in thicker, inequigranular bands or lenses, often enclosing plagioclase and other minerals.

Most *plagioclase* is metablastic [1]), enclosing other minerals (mainly quartz and mica) of the rock. The largest metablast observed measures 1 cm, the size decreases until, far below the limits of macroscopical recognition, plagioclase equals the other major constituents quartz and mica in size and is no longer metablastic but granoblastic. Both lensoid and irregular-equidimensional outlines have been noticed. Enclosed elongated quartz crystals do not indicate a s_i fabric that is parallel with the s_e fabric of the rock in all thin sections studied. When these fabrics do not coincide, the pattern of individual s_i of the metablasts seems to depict an old helycitic fabric and not to be caused by rotation. This does not imply, of course, that in rocks with s_i parallel s_e the presence of such an older fabric is out of the question. Bytownite is the composing plagioclase in one peculiar rock; in all other paragneisses the metablastic plagioclase is oligoclase to (occasionally) acid andesine. Younger albite has developed in this plagioclase generation, especially in the southern half of the map area (fig. 54), avoiding contact with minerals originally enclosed in the more basic plagioclase that surrounds them with narrow rims. It seems, however, that the albite tried to clear itself of foreign minerals: well-developed albite is devoid of inclusions if the original plagioclase did not contain too many of them. The quartz droplets have never been observed in albite. Idiomorphic tiny prisms of rutile and zircon were often noted in albite from specimens found near riebeckite gneiss. Twinning is lamellar on (010) and (001) in oligoclase-andesine, and simple or with some broad lamellae on (010) in albite.

Biotite, enclosed in metablastic plagioclase, is present as small, thin flakes, mostly showing a parallel orientation (indicative of the s_i fabric within the metablast); outside the metablasts the biotites are much larger and especially thicker, only exceptionally oriented parallel to s_e of the rock. Mostly they have random orientations or seem to be oriented oblique or perpendicular to the present schistosity (s_e) of the gneiss. The cordierite nodules and patches of the Pereiras-type gneisses are conspicuously poorer in biotite than their surroundings. Biotite enclosed within cordierite seems resorbed. The colour of biotite is red- or orange-brown in a great majority of rocks; in thirteen, mostly Pereiras-type gneisses, the colour is greenish brown. A few samples bear chlorite instead of biotite, in most others alteration into chlorite is observable but not important. Some Lonsa-type gneisses contain unoriented thin, large flakes of chlorite, a habit not observed with biotite.

Muscovite shows a stronger tendency to lie in the schistosity plane than does biotite. Small and thin flakes (when present) within plagioclase metablasts lie

[1]) See note, p. 117.

parallel to biotites and possible elongated quartz in s_i; in larger flakes outside the metablasts muscovite is often the only mineral responsible for the presence of schistosity planes and consequently of a schistose appearance of the rocks. Muscovite-poor or free specimens are usually massive.
Cordierites of the Pereiras-type seem to contain more muscovite than do plagioclase or quartz in the same zones. The flakes lie parallel to the schistosity; when microfolding is visible, they follow the folds. Bent crystals have not been observed.
Large, lepidoblastic muscovites with irregular terminations, resembling those in muscovite-bearing granitic rocks, abound in paragneisses in the area of cordierite-quartzdiorite and related rocks and near two-mica granites (fig. 53).

Macroscopically recognizable idiomorphic, unaltered *garnets* have only been found in a loose piece of schist W of the Sierra de Galiñeiro. In most other garnet-bearing specimens the mineral is turbid and partially resorbed. They have been found enclosed by quartz and metablastic plagioclase, not rarely by metablastic cordierite (Pereiras-type), once by tourmaline and once by apatite, that in its turn has been enclosed by andalusite. Even when the enclosed garnets are strongly resorbed their alteration products are conspicuously lacking in plagioclase and cordierite metablasts of many rocks. Atoll-garnets or relics of them are not rare. Only two Lonsa-type gneisses contain garnets, one of the two together with, but never completely surrounded by, cordierite. Very small, unaltered and little or not resorbed garnets were recorded too, but generally not in rocks with larger, turbid garnets.

Cordierite has been noted with two different habits connected with textural rock types: Fine-grained aggregates of altered cordierite are characteristic of the Lonsa-type. One cordierite of this type has been observed enclosed by a plagioclase metablast. The cordierite never completely surrounds garnet. Andalusite and sillimanite are commonly found within cordierite.
In contrast with the cordierite in the Lonsa-type, that in Pereiras-type gneisses is present as remarkably unaltered, metablastic crystals with irregular lamellar twins. They enclose much muscovite and ore (ilmenite with hematite lamellae, pyrrhotite, pyrite, chalcopyrite), resorbed oval biotite flakes and turbid, resorbed garnets. One cordierite surrounds plagioclase fragments with exactly the same crystallographical orientations as a neighbouring plagioclase.
Microfolds, indicated by quartz bands and mica flakes (mainly muscovite) have been preserved better within than outside the cordieritic parts, where the coarse recrystallization of quartz and biotite ("Sammelkristallisation" of German authors) obscured the microfolds.

Andalusite alone has been recorded in a few specimens found at widely separated localities, together with cordierite twice in Pereiras-type gneiss and with cordierite and sometimes sillimanite in Lonsa-type gneiss. The mineral is poeciloblastic and xenomorphic except in one specimen which contains idiomorphic prisms with pink pleochroic cores having distinct optical properties.

Three samples collected in the immediate vicinity of two-mica granites in the SW of the map area contain some *sillimanite*. In Lonsa-type gneisses the mineral occurs together with cordierite and andalusite.

No reaction rims giving evidence of instability between cordierite, andalusite and sillimanite have been observed. Some Lonsa-type gneisses contain portions that are very similar to the xenoliths found in cordierite-quartzdiorites.

One microscopical grain of *staurolite*, found in Lonsa gneiss 804 and too small for safe determination, is the only possible occurrence of this mineral within the map area.

Tourmaline with ω olive-green and brown in rocks containing red- or orange-brown biotite and ω blue- to bottle-green in thin sections of gneisses with greenish brown biotite, has been recorded in a great number of paragneisses. In one slide the mineral encloses turbid garnet. Only a few peculiarities as to their distribution could be detected: The mineral is absent in paragneiss enclosed within the main body of the northeastern orthogneisscomplex and also in the fine-grained gneisses between Zamanes and Filgueiras.

Microcline is a minor constituent of the fine-grained gneisses between Zamanes and Filgueiras and of some gneisses occurring as xenoliths in or very near to granitic rocks; it is a major constituent of some paragneisses occurring within or in the vicinity of riebeckite gneiss (fig. 53). It has been noted as an alteration product of plagioclase in chlorite-rich paragneiss. The mineral was never observed in gneisses with cordierite, andalusite or sillimanite.

It has been tried to detect regularities in the distributions of the groups and types of paragneiss by plotting them on tracing-paper thrown over a small-scale geological map. Due to imperfect sampling, but presumably also due to the irregular distributions of the different rock types, such efforts did not have much result. The plotted occurrences of some minerals, already mentioned in the preceding paragraphs, were easier to conceive.

On a plot of equidimensional quartz *versus* elongated quartz in plagioclase metablasts a weak preponderance of the first in gneisses cropping out in the neighbourhood of orthogneiss and riebeckite gneiss is visible. Gneisses with very small plagioclase "eyelets" and some interstitial microcline are restricted to a zone between N of Zamanes in the north and Filgueiras in the south.

Gneisses with plagioclase metablasts commonly exceeding 4 mm are mainly to be found west of the riebeckite gneiss band Galiñeiro-Vigo, especially south of the road Vincios-Zamanes. In the area of the Pereiras-type gneisses rocks with rather large plagioclases are not rare either.

The petrogenetical implications of these observations will be discussed in chapter IX.

VIII. STRUCTURAL FEATURES

Several structural features of rocks in the region under discussion were already mentioned in the petrographical chapters II to VII and need not be repeated here. The observations and facts that will be used in the tectonic interpretation of the area are summarized below. The interpretation itself is incorporated in chapter IX.

Macroscopical observations

Many rocks of the northeastern orthogneiss complex and most riebeckite gneisses display a strong *foliation*. Linear and planolinear textures are frequent in the former, but rare in the latter rocks. The strikes and dips of the foliations show greater variations than the azimuths and plunges of the lineations (see below: π-diagrams). Foliations in rocks of the group of amphibole-biotite rocks and associated gneisses are generally inconspicuous (except in the leucocratic gneisses).

Several outcrops of paragneiss display alternations of bands with distinct colours that reflect varying contents of feldspar, quartz and mica, and these probably represent original *bedding*. *Schistosity*, as brought about either by planar parallelism of micas or by their arrangement in discrete laminae, is not clearly visible or even invisible with the unaided eye in very plagioclase-rich rocks poor in biotite and quartz. Such rocks are apparently massive and often cleave along planes of changing composition. In more schistose rocks it could be observed that schistosity not always parallels bedding. It is possible that during the fieldwork dip and strike of the bedding were measured in some outcrops, although in most of them the dips and strikes were unmistakably those of the schistosity.

Amphibolites in paragneiss have foliations – when present and visible – parallel to the schistosities of surrounding gneiss. When outlines could be observed the amphibolites appeared to occur as lenses with their long diameters in the plane of foliation. Amphibolites in orthogneiss also have foliations – when present and visible – parallel to those of surrounding rocks, but their outlines appeared to be much more irregular (cp. fig. 26).

Folds are common in paragneisses only. In outcrops the amplitudes of the recumbent, mostly isoclinal folds rarely exceed 1m. Larger folds seem to be present if the structural interpretation of the geological map (plate 1) is correct. Very often, it seems to be the bedding that has been folded. Microfolds with amplitudes of a few cm will be described in the section dealing with microscopical observations. In some outcrops the sequence observed may be better described as a series of piled up lenses or boudins of paragneisses with varying compositions than as a succession of isoclinal folds.

The shapes of many amphibolites also point to influence of boudinage.

In riebeckite gneiss shear-folded quartz veins and bands of distinct composition were seen (figs. 16 and 14). Microfolded foliation (amplitudes not exceeding a few cm, fig. 12b) has been noticed at three localities only.

No other folds were found in northeastern orthogneisses, amphibole-biotite rocks and associated gneisses than those constructed from the observed variations of dip and strike of their foliations. They are described below.

Faults interfere with regional orientations of foliation and schistosity. The major faults are rarely exposed. They appear from the disorientation of regional dip and strike and – when they intersect sufficiently distinct rocks – from the displacement of contacts on both sides of the inferred fault. They are generally well-visible on aerial photographs.

It has been attempted to complete the *geological map* (plate 1) with structural data, generalized from about 940 observations of dip and strike of foliations, schistosities, etc. The lines of symbols imprinted upon the colours of the various rocks were drawn parallel to averages of strikes measured in neighbouring individual observation points. In between, the plotted results of selected individual measurements give an idea of the direction and angle of dip of the rock. The density of the observations is greatest in the area around Monte Galiñeiro, smaller between this area and the northern edge of the map and smallest at both sides of the map, since measurements in the valleys were not easy to make. Locally it was impossible to deduce the structure from the few data available. In such parts no symbols were drawn. It should be borne in mind that the procedure of drawing structural contours is correct only in completely flat areas. The presence of relief introduces apparent disconformities, like e.g.: the contact paragneiss-orthogneiss in the valley east of Lavadores and the contact paragneiss-riebeckite gneiss north of the Galiñeiro ridge. At other places, however, accordant contacts are real and only accentuated by the procedure adopted, as, for instance, north of Bembribe

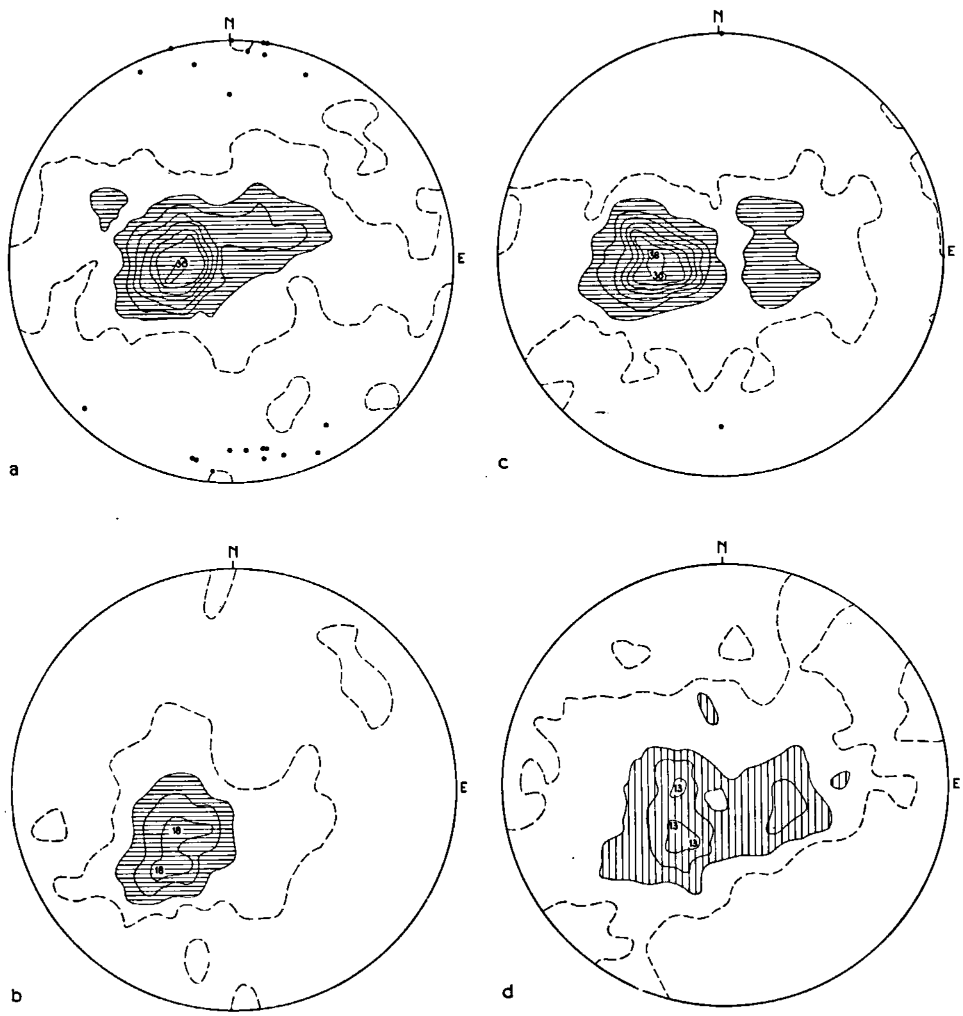
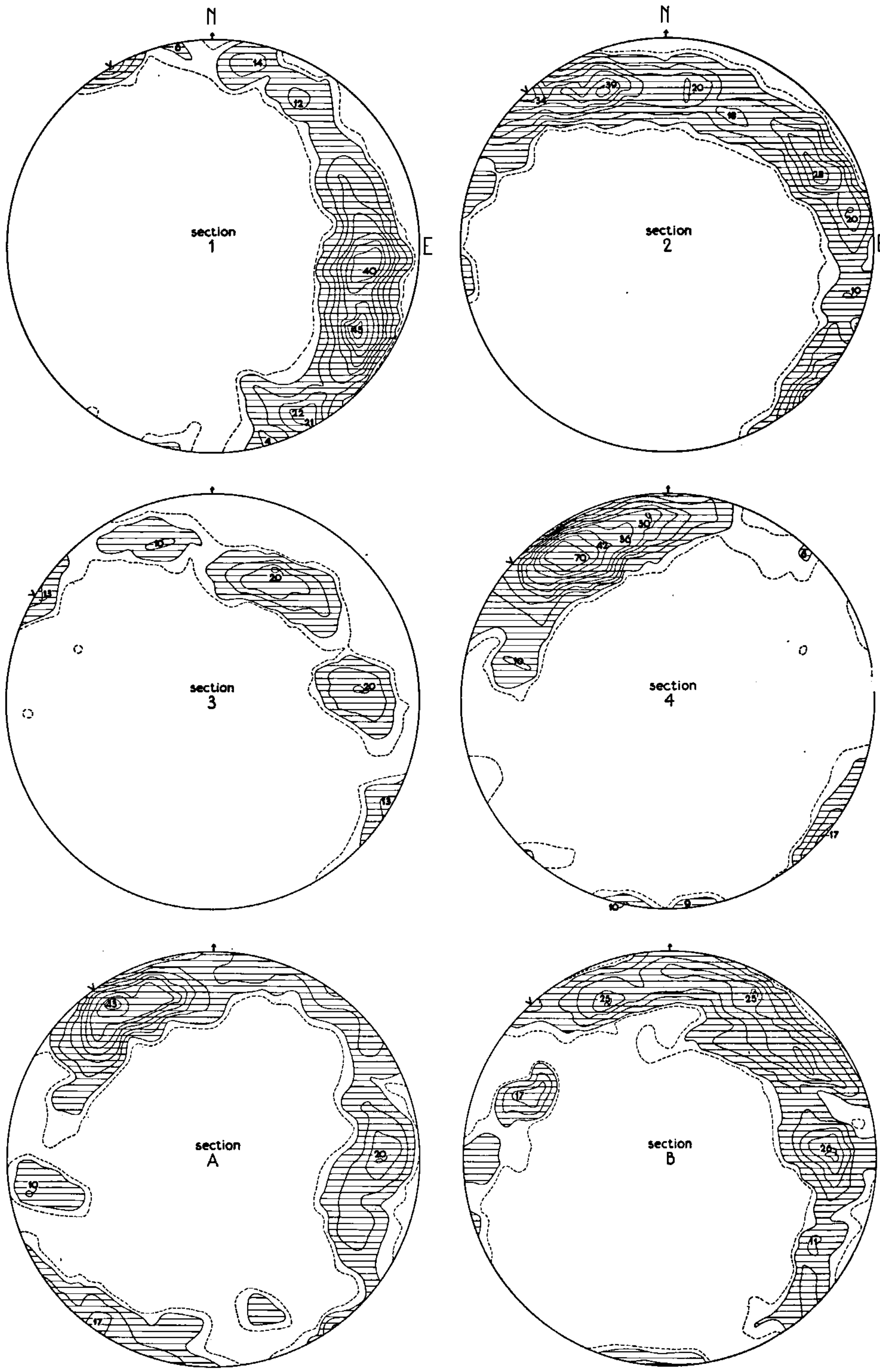


Fig. 45 π-diagrams. a, b: poles of foliations of granite-gneiss, northern and southern half of the area respectively; c, d: poles of schistosities of paragneiss, northern and southern half of the area respectively. Contours at 1, 5, 10, 15, etc. points per 1 % area (a, b, c) and 1, 4, 8, 12 per 1 % area (d). Lineations measured are represented by dots.


N
E
section 1
N
E
section 2
section 3
section 4
section A
section B

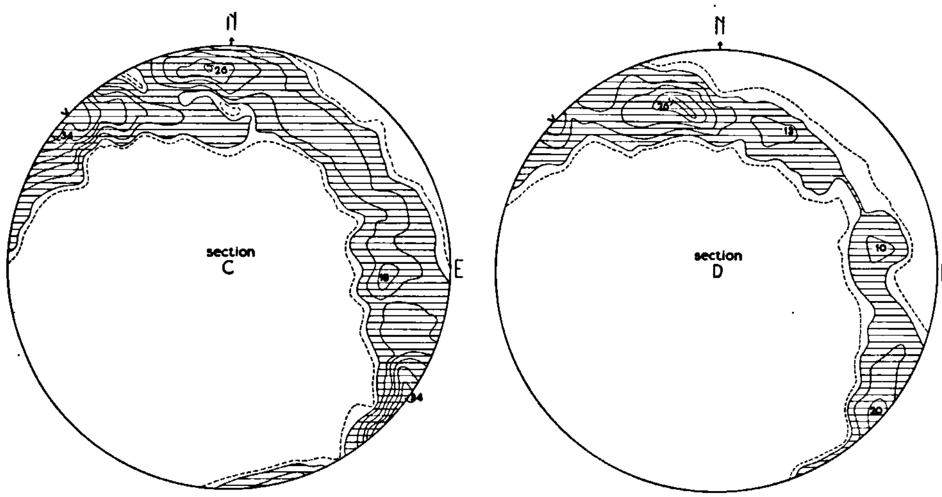


Fig. 46 β-diagrams constructed from intersections of foliation planes of Galiñeiro-type riebeckite gneiss. Explanation in text. Contours at 1, 5, 10, 15, etc. points per 1 % area. Section 4: contours at 1, 5, 10, 15, 20, 25, 30, 40, 50, 60 points per 1 % area.

in the contact orthogneiss-paragneiss. In most places the foliations and schistosities on either side of a contact are parallel with each other or make sharp angles.

Foliations and schistosities have variable dips and strikes especially in the southern and north eastern parts of the map area. The map shows the existence of synforms and antiforms, which are clear especially in the orthogneisses because their foliation is – as far as could be observed – not folded on a smaller scale.

The gneissic rocks of the northwestern quarter of the area dip rather monotonously to the east. The angle of dip, mostly between 20° and 35°, steepens in a narrow zone extending from E of Las Pereiras to the north through the northeastern orthogneiss complex. Curiously, the only isolated paragneiss outcrops within the complex were found exactly in this zone.

East of this zone, most of the folded structures can be seen. The most prominent one is the "Lonsa dome", an elongated orthogneiss body with a N-S axis plunging to the north and south at its northern and southern extremity respectively. Probably the intruding two-mica granite displaced the axis somewhat to the west in the southern part of the dome. The orthogneiss body is completely surrounded by paragneiss, in the west conspicuously rich in andalusite, sillimanite and cordierite (see ch. VII). The paragneiss mantle seems to have been compressed between surrounding orthogneisses at its northern margin. Here, dips are to the NW; east of the airport of Peinador, after a stretch of terrain where no observations could be made, the paragneiss dips to the east. The dip probably changes through vertical from northwesterly to easterly somewhere just west of the airport. In the Lonsa dome and surrounding area the foliations and schistosities partly run perpendicular to the contacts of ortho- and paragneiss. Confusing measurements of the foliation of orthogneiss were made NW of the airport, where a stockwork of cordierite-quartzdiorite to -granodiorite intruded into the gneisses. W and S of the Lonsa dome two synforms could be constructed from the available data; the one east of Las Pereiras has a rather complex shape.

The riebeckite gneiss arc of Monte Galiñeiro can be roughly described as a shallow synform with a somewhat curved N-S axis, plunging to the north. The structure is traversed at several places by faults, which, as appears from their symbols on the map, were not always ascertained in the field. In the southwest, some riebeckite gneisses (among which those of the Zorro-type) with monotonous NW-SE strikes, lie against the gneisses of the arc. The eastern extremity of the arc, west of Abelenda, displays a clear flexure, where it is cut by one of the faults. An actual displacement of contacts could not be seen in the field, although it is very clear where the same fault cuts the western band of the same riebeckite gneiss north of Zamanes. At this locality, the foliation of the riebeckite gneiss of the southern block has been bent to the east and crumpled. A fold axis with azimuth 25° and plunge of 40° S was measured. Within the arc the foliations can be remarkably well traced through the petrographically varied complex of amphibole-biotite rocks and associated gneisses, when vegetation does not inhibit observation. East of summit 658m where the foliation in riebeckite gneiss dips nearly vertically just before the body ends, outcrops are completely absent and the continuation of the foliation could therefore not be traced.

Major faults in the area appeared to strike about NW-SE. The complementary direction NE-SW has been locally observed but never as continuous, topographically expressed features.

Four *π-diagrams* were made of penetration points of lineations and the poles of foliations and schistosities (fig. 45). For this purpose the area has been divided into two parts by an E-W line through Porriño. Data from paragneiss and granite-gneisses (i.e.: NE orthogneisses and riebeckite gneisses) were plotted separately. The diagrams bearing upon the northern part of the map present girdles around a subhorizontal about N-S trending axis. The very low concentrations outside the girdle in the orthogneiss diagram are related to (scarce) measurements on the plunging crest of the "Lonsa dome". The southern diagrams illustrate well the greater variation in dip and strike as compared with the northern ones. The maxima have shifted somewhat to the south, the girdles are wider (paragneiss) or absent (granite-gneiss). A new girdle, around an axis about 60° W of N, seems to appear in both diagrams. The schistosities causing this girdle are probably related to the NW-SE faults.

Because it represents an outstanding structural and petrological unit, *β-diagrams* were constructed from measurements of foliations of Galiñeiro-type riebeckite gneiss. Only data collected in the southern part of the area were used (data from the northern part are few, little variable and therefore not incorporated). Since the number of great circles on one diagram has to be limited to permit evaluation of their mutual intersections and in order to establish whether the maxima found were significant of anisotropy or not, the body was divided into four sections (all containing about the same number of measurements) parallel to the large NW-SE fault and into four sections perpendicular to the preceding ones (fig. 47c). The maxima of the resulting eight β-diagrams (fig. 46) were rotated to the perimeter in two ways around horizontal NW-SE axes to compensate for the supposed influence of the NW-SE faults on the original foliation. The results of a rotation around an average direction of 48° W of N and around maxima (marked by: v) already lying on the perimeter of the diagrams are essentially the same: (figs. 47a and b respectively): concentrations of rotated maxima appear at 10° W of N (the main fold axis B), at 80° E of N (a second axis B′, ⊥ B) and at 30° E of N. The latter "axis" is supposedly related to the fault movements. As exposed above, they took place at least partly in the direction of the strike of the fault. Along such strike-slip faults, rotation is possible around axes in the direction of the dip of the fault. The fact that the axis of microfolding, measured near the fault, north of Zamanes, strikes about 25° E of N may support this statement.

Microscopical observations

The dark constituents in *NE orthogneisses* lie concentrated in planes or rods causing foliation or lineation. The individual crystals, however, have recrystallized and are undeformed; their cleavage planes (biotites) or c-axes (amphiboles) often lie oblique to the direction of foliation or lineation. The light minerals were strongly granulated. In coarser-grained types microcline porphyroclasts have remained as eyes. Quartz bands with rather large crystals and feldspar masses with subparallel extinctions of their constituent grains originated by recrystallization. In several microscopical types (see ch. VI) elongated quartz crystals are present, either in continuous "trains" or dispersed through the rock. They are much larger than the elongated quartz crystals observed in plagioclase metablasts in paragneiss and to be described below.

The *riebeckite gneisses and amphibole-biotite gneisses* generally have a granoblastic fabric in which no evidence of the original cataclasis that caused the foliation can be seen. In the microfolded riebeckite gneisses, mentioned in the preceding section, no cataclastic effects were noted. The same applies to most gneisses with foliations parallel to fault directions and out-

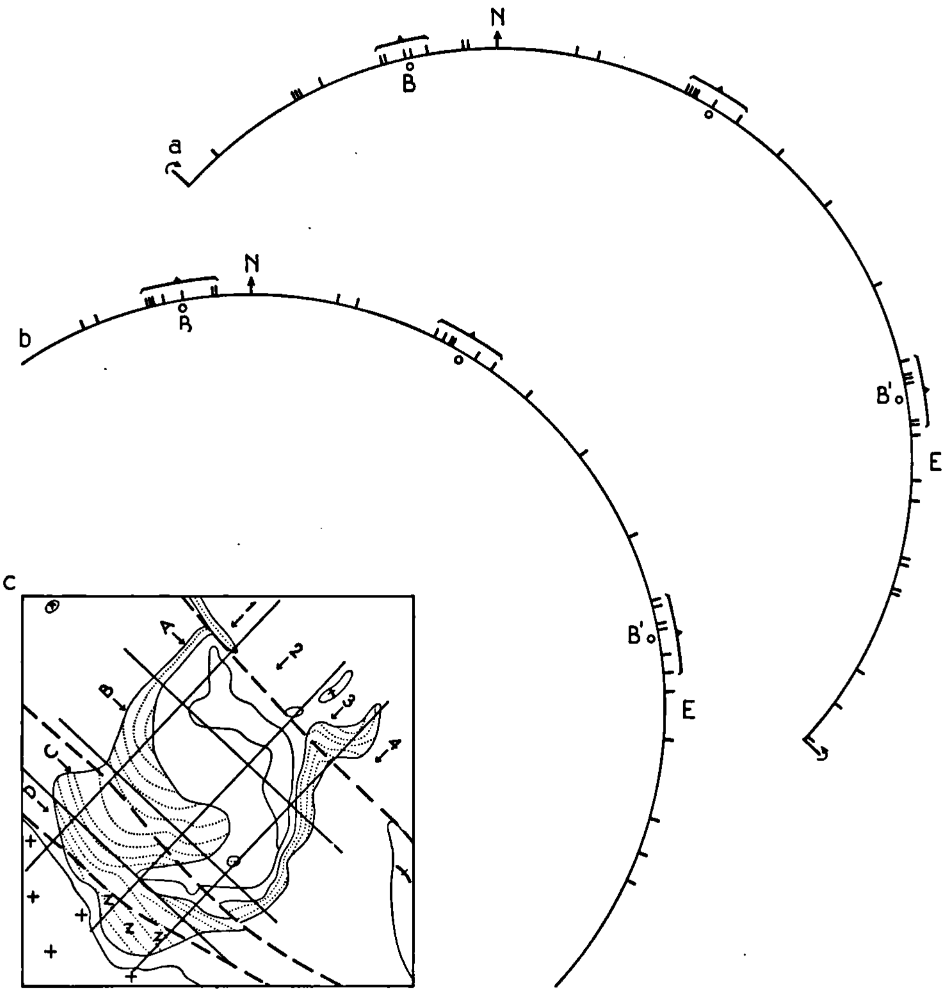


Fig. 47 a, b: rotated maxima of β-diagrams from fig. 46; explanation in text. c: index map of sections.

cropping near fault zones. Only two specimens, collected north of Zamanes and S of col 602 m, have a cataclastic texture imposed upon the granoblastic gneissic texture.

The bedding of *paragneiss*, macroscopically visible as bands of distinct colours, turns out to be caused by the quantitative variation of the main constituents quartz, plagioclase and mica. The relative proportions of these – metamorphic – minerals seem to depict the distinct layers of the original sediment.

As stated in chapter VII, fine-grained, neatly banded rocks were found in many outcrops of paragneiss adjacent to NE orthogneisses (Lonsa-type paragneisses). The different laminae not only have slightly varying compositions but also contain, for instance, quartz grains of distinct habits. "Trains" of elongated quartz crystals lie parallel to the lamination of these rocks.

Paragneisses elsewhere are generally coarser in grain. The fine lamination mentioned above is invisible in most of them, but an alternation of bands with thicknesses of several cm and more is often seen. Also in these rocks the habits of quartz grains present interesting differences.

Only quartz grains enclosed within the plagioclase metablasts serve as criteria since the larger crystals between the metablasts probably crystallized during the metamorphism. The metablasts of many gneisses enclose small isometric or elongated quartz crystals and small biotite flakes. "Trains" of elongated quartz crystals parallel with the banding were also observed in these rocks. The amounts of enclosed quartz crystals may vary in the different bands of a sequence.

Relics of old structures could be noticed occasionally when the metablasts enclose elongated quartz crystals or biotite flakes. They lie parallel in each metablast (s_i) but the s_i of the metablasts together rarely present a coherent picture, since the metablasts have probably rotated during the kinetic metamorphism. A few examples of old structures will be given below. As pointed out in the macroscopical section the visibility of schistosity in paragneiss strongly

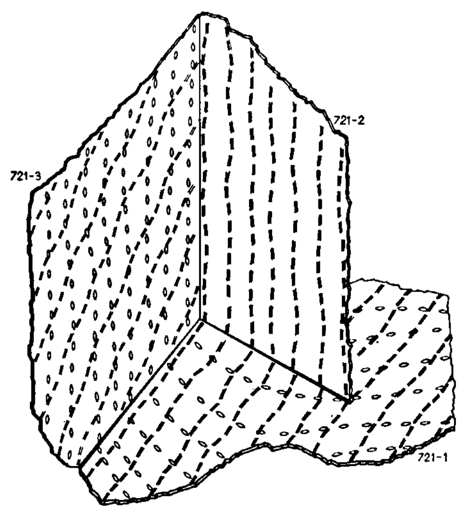


Fig. 48 Orientation of elongated quartz (shown as lenses) enclosed within plagioclase metablasts and of external biotite (dashes) in three mutually perpendicular sections of a plagioclase-rich paragneiss (721).

depends on the quantity of quartz and mica outside the plagioclase metablasts. The shape of the metablasts in the hardly schistose, very plagioclase-rich rocks is irregular, roughly isometric. With increasing quantities of surrounding quartz and mica (both with grainsizes much larger than those of enclosed quartz and mica) the metablasts assume oval outlines, while the "external quartz and mica" are arranged parallel with the external schistosity (s_e). This schistosity has never been observed enclosed within plagioclase. s_e is often not parallel with s_i, both when the individual s_i of the metablasts were rotated and when they were not.
An interesting example of the latter case was found in specimen 721, fig. 48. The external schistosity s_e visualized by biotite, muscovite and elongated quartz undulates around the plagioclase metablasts generally measuring between 1 and 2.5 mm across. The enclosed elongated quartz grains are mostly not longer than .3 mm and not thicker than .1 mm. The s_i of the metablasts together depict a gentle fold in the first of the three thin sections made. Two sections were cut perpendicular to the first and to each other. Thus is was possible to determine the shape of the enclosed quartz grains and to study the relation between s_i and s_e. In the second slide elongated quartz crystals were rarely seen in the metablasts. s_e, however, is well developed. The quartz crystals in the metablasts in the third section were elongated but lying along nearly straight lines. s_e is weakly developed in this section since it was tried to cut it parallel to that direction. A slight tendency for the biotite of s_e to be elongated in a direction oblique to that of s_i was noted (indicated by double lines in fig. 48). Thus, the quartz crystals are disk- and not rod-shaped. They were folded around an axis that roughly

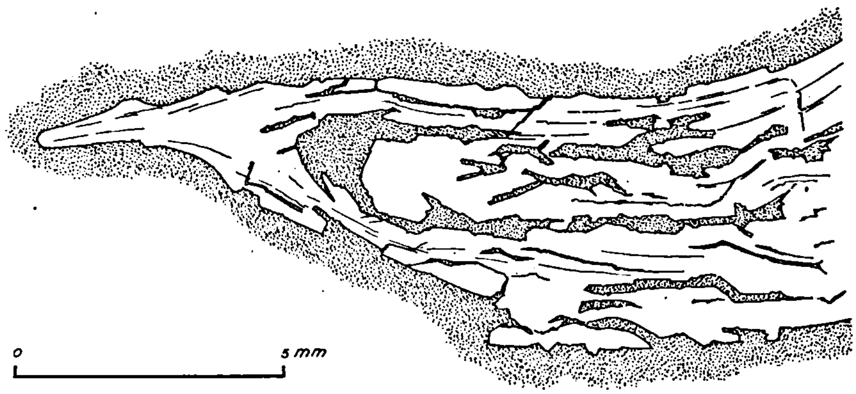


Fig. 49 Isoclinally folded quartz bands in cordierite nodule. Pereiras-type cordierite gneiss (663).

parallels the intersection of slides 2 and 3. The sample was too small to determine the amplitude of the s_i fold or to establish whether s_e constitutes the axial plane cleavage of the s_i fold or bears no direct relation to it. Macroscopically the whole structure is invisible.
A folded banding with an amplitude of a few cm was noticed in sample 173. In thin section the sequence proved to consist of quartz bands and bands of plagioclase metablasts, some richer in "external" mica than others. The great majority of the "external" micas in the whole section was lying with the basal cleavage plane parallel to the axial plane of the folds.

"Trains" of elongated quartz crystals parallel to the external schistosity were seen in rocks with elongated quartz grains and in rocks with isometric quartz enclosed in plagioclase metablasts. "Snowball" structures are absent in metablasts.

In general, microfolds are not rare in paragneisses. They are only well visible in thin sections of Pereiras-type cordierite gneisses, enclosed within cordierite nodules. In other paragneisses microfolding is irregular and seems to be obscured by later recrystallization. Except in the cases mentioned above it is rarely possible to establish unambiguously whether one

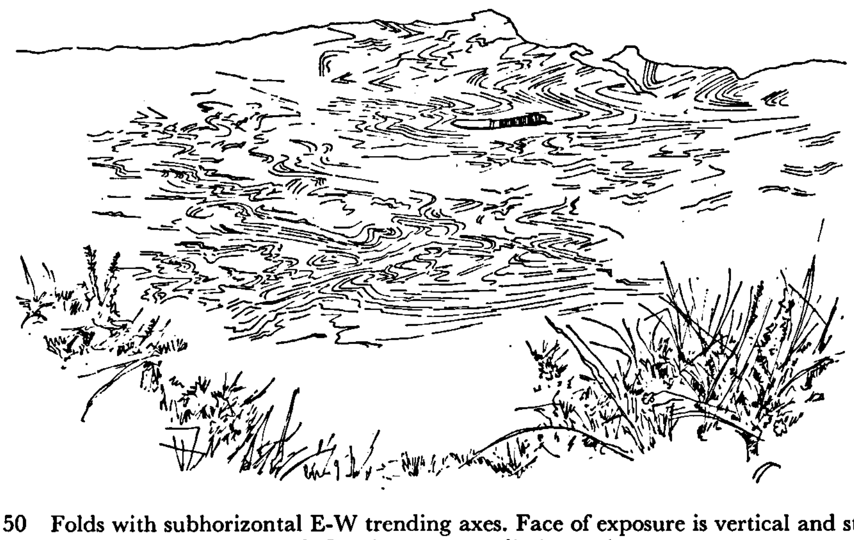


Fig. 50 Folds with subhorizontal E-W trending axes. Face of exposure is vertical and strikes N-S. Pereiras-type cordierite gneiss.

observes microfolded bedding or schistosity. This difficulty arises especially in the case of microfolded quartz bands, since they were observed to occur parallel to the bedding whereas others were parallel to the schistosity.
The pigeon-egg-sized cordierite nodules of the Pereiras-type cordierite gneisses contain little biotite and much muscovite in contrast with the surrounding cordierite-free biotite gneiss, in which muscovite is rare. Isoclinally folded quartz bands lie parallel to the schistosity (fig. 49). The axes of these folds, which are not macroscopically visible, tend about N-S. Most cordierites of one nodule have subparallel extinction directions.
Folds with subhorizontal ± E-W running axes were locally observed on Las Pereiras (fig. 50). Recrystallization prohibited establishment of the moment at which this fold-type was generaled. Because bent micas are absent, it cannot be a very young fold.

In most paragneisses and some amphibolites weakly to non-oriented grains of respectively large biotite and cummingtonite are present. When they are oriented, the biotites rarely lie parallel to the schistosity but rather in a direction oblique to it ("cross-biotites").

IX. PETROLOGICAL AND TECTONIC SYNTHESIS

In the following discussion of the history of rocks found in the investigated area only petrographic data of immediate importance to the explication of observed or interpreted phenomena are given. The same sequence from young to old rocks has been adopted as in the preceding chapters with the exception of the section amphibole-biotite rocks and associated gneisses, which have so many aspects that it is essential to know the genesis and history of all other rocks before discussing them. Actions of rocks upon others will be dealt with in the section concerning the rocks that underwent these influences. Some remarks about the grade and age of the hercynian metamorphism and about the complex of pre-hercynian granite-gneisses as a whole conclude the chapter. Plate 3 is an attempt to summarize the data presented in this chapter in tabular form.

THE HERCYNIAN GRANITES

The dating of the granitic rocks found in the area under discussion as hercynian is based upon the following facts:
Apart from their similarity to granites in Portugal that could be dated as belonging to the hercynian orogeny because they are intrusive into older or discordantly overlain by younger paleozoic sediments, Rb-Sr age determinations were made of whole rocks and minerals of several Portuguese and one NW Spanish granite, all considered in their regions to be the youngest present because of their intrusive relations towards other granites (Table 19). On the other hand, the oldest true granite encloses xenoliths of orthogneiss which contains a biotite, that recrystallized after the formation of the foliation and also has a hercynian Rb-Sr age (table 20). Two-mica granite is intrusive into riebeckite gneiss, carrying biotite which yields a hercynian Rb-Sr age as well (table 20). The whole series of granites in the Galiñeiro area must therefore necessarily be of hercynian age.

The youngest granite in the area is the small part of the large Porriño-Monção *coarse-grained biotite granite* pluton (fig. 1, 4g). The granite is clearly post-tectonic, with sharp contacts and without xenoliths. It carries microcline, plagioclase (basic oligoclase to albite-oligoclase), quartz, dark brown biotite, idiomorphic zircon, allanite (Parga-Pondal, 1933), apatite, titanite, fluorite, ore and alteration products like chlorite, sericite, epidote, prehnite and calcite. No pegmatites were found in the investigated area. A pegmatite with biotites up to a few dm across has been reported by O. Martinez Rodriguez (oral communication) to occur in the vicinity of Puenteareas. Similar granites and also more porphyritic types ("coarsely porphyritic biotite granites" of the Amsterdam school) occur at many places in Galicia and N Portugal. Oen Ing Soen (1960) discussed the intrusion mechanism of these post-tectonic biotite granites.

Age relations between coarse-grained biotite granite and *two-mica granites* could not be established in the author's area; elsewhere, the latter appear to be intruded by the former. The two-mica granites (composed of albite, microcline, quartz, muscovite, biotite, apatite, turbid irregular and rounded zircons and ore) are very common in W Galicia and in N Portugal. Both these granites and the afore-mentioned younger coarse-grained to porphyritic biotite granites have such constant properties that the differences as summarized by Brink (1960; p. 66) for rocks near Vila Real, Tras-os-Montes, N Portugal may be quoted here without any restriction:

a. Muscovite is present in a very subordinate amount in the younger granite, but is the principal mica in the older granites. The colours of biotite are different in the two granites. In the younger granite its pleochroism is stronger, and in its darkest position it shows brown to black colours, whereas in the older granite it is reddish-brown.
b. The early plagioclase of the older granite is albite to albite-oligoclase ($\pm$ An_7–An_{13}), whereas that of the younger granite is more basic (up to An_{28}). Decalcified rims are of common appearance in the younger granite, but are infrequent and less distinct in the older granite.
c. The development of interstitial microcline and late albite, i.e. the development of late blastic feldspars, is more pronounced in the older granite than in the younger. The distinction between early and late plagioclase is very difficult and not always possible in the older granite. The ratio between the total amount of plagioclase (albite included) and potash feldspar appears to be > 1 in the older granite and < 1 in the younger.
d. Calcium-bearing alteration products as titanite, epidote and to a lesser extent prehnite are of frequent occurrence in the younger granite, but are scarce in the older.
e. Andalusite and sillimanite were only encountered in the older granite. The presence of these minerals and the abundance of muscovite seem to indicate that the older two-mica granite crystallized from a magma relatively richer in alumina [,.......].
f. The groundmass of the younger granite is much coarser than that of the older, fine- to medium-grained two-mica granite.

The idiomorphism of zircon, the presence of allanite and the much more frequent occurrence of myrmekite and perthite in the younger granites could be added. Andalusite has not been found in the author's area, but occurs in two-mica granite W of Pontevedra (Rengers, 1965).

As stated in chapter II six types of two-mica granite were distinguished in the field (fig. 4a–f). None of these have been gneissified or phyllonitized; a weak orientation of biotite has been observed in a few outcrops. Only a few of them have contacts with each other, contact relations that permit the establishment of age relations were seen only once, viz. between coarse-grained equigranular and medium-grained inequigranular granite at a locality just outside the map area, S of Vincios. The latter granite is finer-grained against the contact, whereas the former is coarser than normal. This leads to the conclusion that the medium-grained granite is younger than the coarse-grained. The intrusive character is very clearly visible at the W shore of La Guia, where rafts of paragneiss are floating in medium- to coarse-grained equigranular granite (fig. 5). Elsewhere, contacts are also sharp except on the E slopes of San Bartolomé and Cepudo where a nebulitic biotite gneiss developed at a contact with riebeckite gneiss (cp. next section).

Several observations point to the fact that the present appearance of the two-mica granites was partly caused by late- or post-magmatic processes: Plagioclases now have only very weak or no zonary structure. Sericitized cores or zones indicate that a zonary distribution of anorthite originally existed. Some small plagioclases enclosed within microcline are clearly zonary, unaltered and have cores with up to 16 % An, though in plagioclase outside microcline the highest percentage measured is 11 %.

Muscovite is present as thick randomly oriented lepidoblasts with often very irregular terminations of their basal planes. Not rarely they are „thicker than they are long" and enclose sillimanite needles. Specimen 676, collected outside the area represented on the map, SE of Gondomar, contains oscillating zonary plagioclase (cores of acid andesine, rims of acid to intermediate oligoclase) and very imperfect muscovite

poeciloblasts, suggesting an initial stage in the formation of the lepidoblasts common in normal two-mica granites.
Albitization and formation of muscovite lepidoblasts with or without sillimanite were extensively studied and described by students from the Municipal University of Amsterdam (cp. references in the introduction of chapter II). As in Portugal, Ca-bearing alteration products were not observed in Galician two-mica granites.

Chemical analyses of two-mica granites show a considerable excess of alumina when their norms are calculated (Torre de Assunção, 1962; Priem, 1962, p. 108). As argued by Priem (loc. cit.), the excess is probably due to assimilation of alumina-rich wall rock during intrusion of a more normal granitic magma.

Two-mica granites are accompanied and cut by a greater number of *pegmatitic dykes* than the younger Porriño granite. Especially around the coarse-grained equigranular type, outcropping SW of Monte Galiñeiro, large quantities of *pegmaplite* (see note p. 14) were seen, containing several of the minerals muscovite, garnet, tourmaline, beryl, biotite, rare accessories and ore (a.o.: wolframite). *Pegmatites* generally have more simple compositions and contain either biotite or muscovite in predominating amounts. *Muscovite-quartz-albite rocks, tourmaline-quartz veins and tourmaline enrichments* in paragneiss adjacent to granite or pegmatite are other features related to the two-mica granites, though this could not be proved in the case of occurrences in paragneiss distant from outcropping two-mica granite. In the same way it is not quite clear to which granite suite the *granite-porphyry*, found E of the muscovite granite body, belongs.

The *muscovite granite* encloses blocks of megacrystal granite and is intruded by two-mica granite. It is therefore intermediate in age between the latter two. It is a medium-grained aplitic granite (fig. 4h) with albite (0–5 % An) in non-zonal hypidiomorphic crystals, muscovite (without lepidoblastic habit), garnet, tourmaline, beryl and large apatite.

Megacrystal granite (fig. 4i, k) strongly resembles the coarsely porphyritic biotite granites from N Portugal, both in outcrop and in mineralogical composition. Nevertheless the field relations: megacrystal granite enclosed by muscovite granite (S of Vigo) and two-mica granite (N of the Ria of Vigo; Hensen, 1965) and also the fact that the granite is weakly cataclastic, demonstrate very clearly that this granite does not belong to the youngest granites in the area.
Especially in excavations at building-sites in Vigo it could be observed that this granite encloses many blocks of orthogneiss or paragneiss (more to the west), that often retained their regional dip and strike and therefore should be considered as septa or roof-pendants. Megacrysts are parallel to boundaries of enclosed rocks and thereby demonstrate the existence of a flow-structure.
Contacts are sharp. In xenolith-free outcrops, the megacrysts lie in subvertical about N-S striking planes, when oriented at all.
The megacrysts enclose plagioclase and biotite crystals oriented parallel to their outlines. The groundmass is granodioritic with hypidiomorphic plagioclase (cores with up to 43 % An, idiomorphic against quartz), microcline, reddish brown biotite, a few flakes of muscovite, apatite, idiomorphic zircon and ore. Tourmaline-bearing pegmatites were noted in megacrystal granite on the western slope of the Castro of Vigo. Since two-mica granites seem to be present at rather great distances, their co-genetic relation with the enclosing granite is more probable.
Megacrystal granite and aplitic muscovite granite are tentatively grouped together on the ground of the common occurrence of idiomorphic to hypidiomorphic plagioclases in all of them. They were moreover observed together N of the Ria of Vigo (Hensen, 1965) and at several places NW of Noya (Avé Lallemant, 1965).

The relative age of the *cordierite-quartzdiorites and related granodiorites and granites* is uncertain, since no other granite is found in their area of distribution. Like megacrystal granite, *cordierite-quartzdiorite* was observed to occur as a "stockwork", mainly intrusive into orthogneiss. In some occurrences elongate dark-coloured aggregates were seen (fig. 4 *l*), which under the microscope turned out to consist of combinations of the minerals cordierite, andalusite, sillimanite, biotite, quartz, ore and minor amounts of plagioclase, corundum and spinel. Some Lonsa-type paragneisses proved to contain similar alumina-rich portions.

Microscopically the cordierite-quartzdiorites are remarkable rocks with idiomorphic cordierites often exhibiting sector twinning (fig. 9), (hyp)idiomorphic plagioclase (oscillating zonary (mostly 30 → 10 % An, rims of 2 % An), occasionally enclosing cordierite, figs. 7, 8), interstitial quartz, biotite, and irregular implication intergrowths of ragged muscovite, quartz and some acid plagioclase (fig. 6). According to Schreyer & Yoder (1961; p. 148) cordierites in igneous rocks as crystallization products of a magma usually have the properties as outlined above. The acid rims of plagioclases enclose myrmekitic quartz vermicules, though no microcline is visible in the slides. Only one sample is microcline-bearing; the myrmekites in plagioclases against these microclines are not different or more strongly developed than those in microcline-free rocks.

Granite and granodiorite were assumed to belong to the same group as the quartzdiorites because they occur together in one limited area and contain the same (hyp)idiomorphic plagioclases (An_{25-15}, rims albitic) and interstitial quartz as the quartzdiorites. They differ from two-mica granite by the habits of plagioclase, the interstitial occurrence of quartz and microcline and a higher biotite content (fig. 4m). Irregular intergrowths are again not rare, here between microcline and quartz, with or without the participation of muscovite. The normal myrmekite development is visible in these rocks, occurring alone in outgrowths upon plagioclase in contact with interstitial microcline.

The inhomogeneous character of especially the cordierite-quartzdiorites and the occurrence of aggregates of alumina-rich minerals in Lonsa-type paragneisses (and as "restites" in the former) seem to indicate that these rocks crystallized not very far from where they were generated. The clearly discordant mode of intrusion with sharp contacts and the content of idiomorphic cordierite, plagioclase, zircon and apatite condition that the rock was, at least for a great part, in a molten state at the time of intrusion. Besides, the rock is intrusive into orthogneiss, in which the alumina-rich melt certainly cannot have originated. In the narrow paragneiss septum between "Lonsa dome" and the main body of orthogneiss to the west no phenomena of migmatization were observed either. The relation between Lonsa-type paragneisses and the cordierite-quartzdiorites will be discussed in the section on paragneiss, further below.

The experiments of Winkler & von Platen (1961) demonstrate that anatectic melts of tonalitic composition are formed when greywackes are sufficiently heated in the presence of water. The first anatectic liquid has an aplitic composition. Higher temperatures cause more rock to melt, the composition of the liquid changes via granitic to granodioritic and, at higher temperatures and appropriate compositions, becomes tonalitic. The experiments were performed at 2000 atm. P_{H_2O}. The unfused rest contains varying quantities of quartz, plagioclase, cordierite, biotite, ore and sillimanite-mullite. Upon crystallization, the anatectic aggregates, generated in these experiments, all contain K-feldspar. This mineral, however, is generally lacking in the cordierite-quartzdiorites under discussion, muscovite occurring instead.

A.o. Segnit & Kennedy (1961) and Seki & Kennedy (1965) provided data of a "stability curve" of K-feldspar and muscovite in the P_{H_2O}-T diagram, fig. 51. This curve is valid only when the system contains much water because the alteration of K-feldspar into mica yields a fluid phase containing potassium and silica. When the concentration of K and Si dissolved in water reaches a certain value, further alteration does not take place. Completion of the reaction is therefore only possible if sufficiently large amounts of water are present (Seki & Kennedy, 1965; p. 1077). The diagram (fig. 51) further represents the stability fields of Mg-cordierite after Schreyer & Yoder (1964) and of andalusite, sillimanite and kyanite after Schuiling (1962).

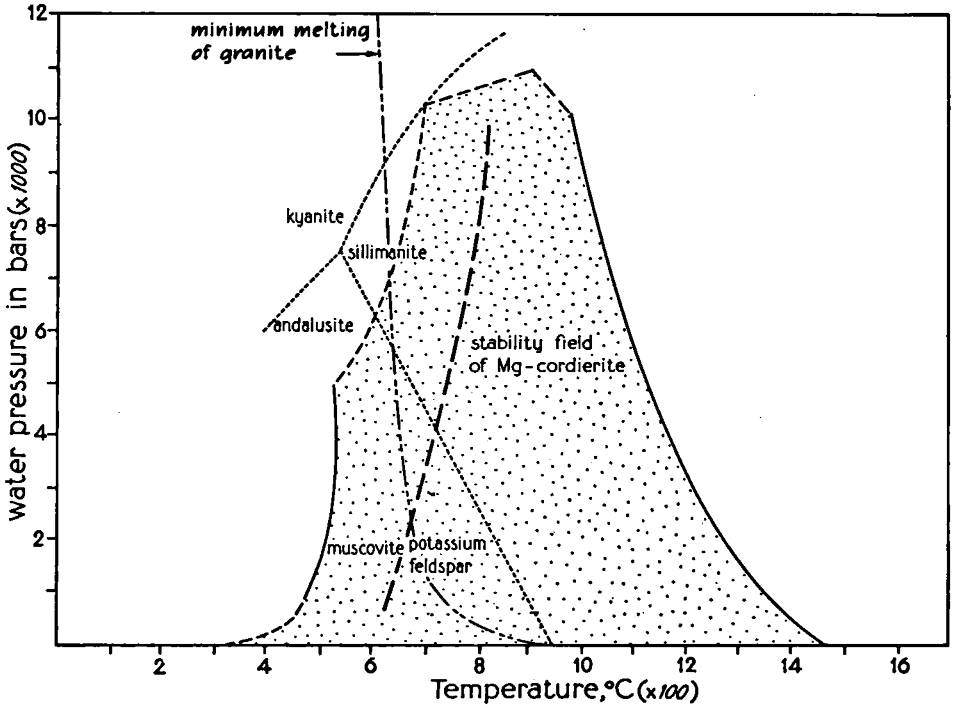


Fig. 51 Stability relations of Mg-cordierite (after Schreyer & Yoder, 1964), Al_2SiO_5 polymorphs (after Schuiling, 1962) and of muscovite and potassium feldspar (in the presence of excess water; after Seki & Kennedy, 1965). Explanation in text.

If these experimentally determined curves may also be used for a tentative explication of the assemblages in natural systems, it appears that a high P_{H_2O} causes muscovite to crystallize instead of potassium feldspar. Because sillimanite is mostly present in the cordierite-quartz-diorites and its "restitic" fragments, P_{H_2O}-T conditions must have been generally within the stability field of sillimanite. The mineral assemblage now present in the cordierite-quartz-diorites can be either primary or secondary.

If it were a primary assemblage, the minimum P_{H_2O} at which the rock would have crystallized would be that of the intersection of the K-feldspar-muscovite and andalusite-sillimanite phase boundaries (± 4kb). If the temperatures of anatectic melting of greywackes, found by Winkler & von Platen (1961), may be applied in this case of natural melting, the temperature of the phase-boundary intersection (± 720°C) would be too low for the formation of a quartz-dioritic melt. Thus, both pressure and temperature should have been higher.

If, on the other hand, the potassium feldspar-free assemblage of the cordierite-quartzdiorites does not reflect the primary crystallization product from the tonalitic melt, P_{H_2O} of that crystallization could have been lower, giving rise to a cordierite- and some potassium feldspar-bearing granodiorite to quartzdiorite. A subsequent rise of P_{H_2O} to a value above the phase boundary would have caused potassium feldspar to alter according to the equation: potassium feldspar + sillimanite + H_2O → muscovite + quartz. Since the cordierite-quartzdiorites are characterized a.o. precisely by the occurrence of complicated intergrowths of quartz and muscovite (fig. 6), it is not impossible that their formation is indeed secondary and caused by a late or post-magmatic rise in P_{H_2O}.

If the experimental temperatures, found by Winkler & von Platen (1961), would turn out to be somewhat lower in nature, for instance because other volatiles than H_2O are present as well, this would not basically modify the reasoning set out above, as appears from fig. 51.

The association of granite and granodiorite with cordierite-quartzdiorite, reflecting distinct melt compositions, has probably been caused by either different pre-anatectic rock compositions, contamination in the anatectic stage or by a somewhat less elevated temperature of formation of the granitic and granodioritic melts (Winkler & von Platen, 1961). The microcline content in these rocks was so high compared with that in the quartzdiorites that the quantity of water present did not permit its complete alteration into muscovite. Quartz-muscovite-microcline intergrowths are indeed present in the granites and granodiorites (cp. chapter II).

Mode of intrusion of megacrystal and two-mica granites

Although the hercynian granites are hardly cataclastic, they intruded into the investigated area before the complete termination of the hercynian penetrative movements since phyllonitized megacrystal granites are known to occur N of the Ria of Vigo (Hensen, 1965), while more gneissic specimens than are to be found in the author's area were also collected by him in the south, just over the Portuguese frontier, E of Vila Nova de Cerveira (fig. 1) (Torre de Assunção, 1962; p. 31). The same applies to the two-mica granites. The late hercynian phyllonitization (Avé Lallemant, 1965) did not deform the rocks in the Galiñeiro area, which is therefore suitable for an investigation of the older history of the hercynian orogen in Galicia.

As stated in chapter I, the intrusion of the megacrystal granites followed the development of migmatites and anatexitic granites but preceded that of types of the two-mica granite series with a more intrusive character. It is therefore improbable that both granites have a common origin.

Because of the more evolved magmatic character of the megacrystal granite and related rocks, they seem to have formed at greater depth than the two-mica granites. Their distribution in elongate bodies along major tectonic lineaments, both in western and in eastern Galicia (partly visible on fig. 1), supports the hypothesis that they owe their emplacement to the existence of these faults [1]).

It is highly desirable to discriminate also in Portugal between the older megacrystal granite suite and the posttectonic biotite granites. When the former are undeformed, distinction is difficult. Perhaps the colour of biotite (reddish brown v. dark brown) and the presence or absence of accessories (allanite?) may serve as criteria.

Two-mica granites have outlines that are less indicative of an origin through intrusion from greater depth. Their magmatic character is less pronounced and the alumina excess suggests that its emplacement was accompanied by the assimilation of wall rock. More to the north (e.g. in the area around Sierra de Outés, 8 km NNW of Noya; Avé Lallemant, 1965) the presence of inhomogeneous anatexitic two-mica granites demonstrates that at least some two-mica granites did not migrate

[1]) In the southern half of Galicia the N-S trending zone of pre-hercynian metasediments and granite-gneisses is not at all clearly limited by faults as is the case in the northern half. The conclusion that all megacrystal granite intruded along a fault is based on an extrapolation of the circumstances in the north and on the extreme homogeneity of megacrystal granite.

far before crystallizing and this is probably valid for all two-mica granites, though in different degrees.

Both megacrystal granite and two-mica granite were cut by faults, that also traverse riebeckite gneiss. As will be argued in the next section, it can be deduced from the displacements and repeated movements along the faults that the megacrystal granite and two-mica granite suites intruded during a period of prevailing N-S compression, which probably facilitated the opening of fissures along which the megacrystal granites could rise.

THE RIEBECKITE GNEISSES

The riebeckite gneisses strongly underwent hercynian penetrative deformation and as a consequence have a pronounced foliation in the field. The investigation of thin sections revealed, however, that the microscopical appearance of the rocks is determined largely by hercynian recrystallization. It seems therefore suitable to deal first with the foliation of these gneisses and treat the mineralogical and petrological history next. The pre-hercynian characteristics, as far as they can be deduced from their actual state, and some general considerations conclude this section. For chemical analyses of riebeckite gneiss and some geochemical considerations the reader is referred to the section petrochemistry of chapter III (tables 9, 10, 11, 13).

Foliation

Planar foliation, as already stated, is well developed; only around hill 658 m it is somewhat weaker. Near La Guia linear rocks were found. The foliation is always subparallel to the schistosity in neighbouring paragneisses and amphibole-biotite gneisses, also when it is not parallel to the contacts.

Apart from locally restricted microfolds, the foliation has been folded on a regional scale only. As can be seen on the geological map the fold roughly consists of a syncline with a N-S axis, that has been gently curved along an E-W axis. Both axes ($\pm$ 10° W of N and 80° E of N) appear on plots constructed from β-diagrams (figs. 46, 47a, b). Though the foliation is flat, shear-folds were observed in quartz veins, pegmatitic bodies and bands of distinct composition locally present in riebeckite gneiss (figs. 16, 14). The deformed habit serves as a criterion in distinguishing older and younger pegmatites, the latter being clearly discordant and unaffected by tectonization.

The regional dip and strike were locally disturbed by the influence of transcurrent, mainly NW-SE striking, faults. The foliation near these faults is steeper and generally striking subparallel to the fault direction. N of Zamanes where the western gneiss-band makes a large angle with this direction, the foliation has been microfolded (fig. 12b; azimuth of axis: 25° E of N, dip 40° to S) and dragged to the east, indicating a dextral movement along the fault. Remarkable is the fact that further SE along the same fault the eastern gneiss band has been flexured without the formation of microfolds. The dextral displacements prove that the faults were caused by a N-S compression. The third B axis (30° E of N) derived by construction from the β-diagrams (fig. 47a, b) might be related to the influence of the faults upon the directions of the foliation in their immediate vicinity (cp. the fold axis mentioned above).

From the study of thin sections reported below the conclusion could be drawn that movements along these faults took place twice. Microfolds were also observed on the E slope of San Bartolomé and on the summit of La Guia. It could not be established by which action they were caused.

Directing the attention now to the *mineralogy and petrology* of the riebeckite gneisses it should be remarked that the present mineral assemblage of these rocks is determined partly by original compositional differences and partly by changes that took place during metamorphism of the rocks.

"Normal" riebeckite gneisses

First the "normal" gneisses with varying quantities of aegirine, lepidomelane or astrophyllite, further composed of albite, microcline, quartz, zircon, fluorite, ore, xenotime and the less constant accessories pyrochlore, apatite, siderite and allanite will be dealt with. The macroscopical foliation of alternating dark- and light-coloured bands a few mm thick is re-encountered in thin section: dark minerals tend to be concentrated into bands, though not very strictly, while discontinuous bands of quartz crystals lie in between. Granoblastic fabrics of the light-coloured minerals without quartz in bands were observed occasionally.
Two types of light mineral textures can be distinguished: the *Galiñeiro-type* contains porphyroblastic albite as the largest mineral (1–9 mm) with quartz and microcline occurring in granoblastic mosaics of smaller crystals (usually .5–1 mm) between the albites, whereas in the *Zorro-type* microcline is generally the largest mineral (length max. 5 mm), albite is somewhat smaller, while quartz occurs as rather coarse grains (about 3 mm) in irregular bands. As a consequence of these differences and also of the fact that the dark minerals of the Zorro-type rocks are less conspicuously concentrated into bands the macroscopical appearance of rocks of both types is distinct (figs. 12a and c).

Albite, present as comparatively large untwinned or simply twinned porphyroblasts surrounding a.o. microcline, quartz (also "trains" of quartz parallel to the foliation!) and only small amounts of dark minerals, is one of the youngest minerals in riebeckite gneiss. Often one individual of a simple twin is much larger than the other one. Grains of aegirine, lepidomelane or astrophyllite were noted within albite, even when these minerals do not occur elsewhere in the rock. Some specimens contain parts that consist exclusively of oval albites with interstitial fluorite and riebeckite.
Even where the foliation has been curved, steepened, microfolded or flexured by faults the albites have the same undeformed aspect, proving that these events took place before their crystallization. Cataclastic albites (and other minerals) were noted in two specimens collected where the two major faults were located by mainly indirect observations, thus indicating that movement along these faults took also place upon discrete planes after crystallization of the albite.
Because megacrystal granite and two-mica granite enclose blocks of recrystallized orthogneiss and are intrusive into riebeckite gneiss respectively, both granites must be younger than the recrystallization of the gneisses, which in turn is younger than the first fault movement as argued above. On the other hand the second fault movement traverses the granites too. The intrusion of the granites must therefore have taken place between the two fault movements caused by N-S compression.

Since microcline has been found enclosed within albite porphyroblasts, especially in Galiñeiro-type gneisses, the mineral should have crystallized before albite. In thin section the mineral commonly shows very sharp cross-hatch twinning; perthite is rare. Chemical and X-ray analyses revealed that the mineral (concentrated from a sample not specially selected for this purpose) is a nearly pure maximum microcline (table 2).

The large microclines of the Zorro-type gneisses have less pronounced cross-hatch twinning, are slightly perthitic and enclose small microclines. Albite does not form homogeneous porphyroblasts but aggregates of subparallel-oriented blastic grains. The large microclines seem to be slightly deformed, they are undulose and, when ruptured, the fractures are lined with small albites and microclines. From the properties of quartz rods enclosed within microcline and adjacent albite it could be deduced that also in these rocks albite was the latest crystallizing feldspar.
In contrast with the granoblastic Galiñeiro-type gneisses those of the Zorro-type have a blasto-cataclastic fabric. The presence of undulose large microclines might be explained in two ways:
1. The large microclines are porphyroblasts; their deformation is due to stresses that did not act upon Galiñeiro-type rocks;
2. The large microclines are porphyroclasts; fragments of the broken original large microcline crystals that had rotated during fracturing recrystallized into enclosed distinctly oriented grains.
Since Galiñeiro- and Zorro-type gneisses are exposed in each other's immediate vicinity it is improbable that the latter have been subjected to an extra deformation as compared with the former. The author therefore prefers the second explanation.

Exsolution of feldspar

One of the most striking results of an extensive survey of the literature on per-alkaline granites is the fact that all described granites contain perthitic feldspar with little or no primary albite. Since the riebeckite gneisses of the area under discussion are considered as intrusive rocks, as will be argued further below, they should by analogy have contained perthitic feldspars originally. It was probably the hercynian deformation, also causing the foliation, that triggered off the complete separation of the phases albite and potassium feldspar, already unmixed into perthite, and did so very effectively as appears from the chemical and X-ray data on albite and microcline from Galiñeiro-type gneiss (tables 1, 2). As mentioned above, Zorro-type gneisses generally remained slightly perthitic.

The unmixing of perthitic alkali feldspars into separate albite and potassium feldspar has repeatedly been reported in the literature (a.o. by Buddington, 1939; Tuttle, 1952; Harker, 1954).
Harker, in his description of alkali feldspars in granitic gneisses of the Carn Chuinneag-Inchbae complex, Scotland, remarks in his conclusions (p. 135):
'It appears that as the rocks become more deformed, recrystallization was facilitated and the perthites were able to clear themselves into two well-separated phases, so that the orthoclase and microcline perthites have eventually become replaced by non-perthitic microcline in the most foliated gneisses'. Buddington underlines the fact that this kind of unmixing is not produced by cataclasis alone but only when it is followed by recrystallization generating granoblastic gneiss. Recrystallization alone, on the other hand, is not able to produce unmixing either; it has to be preceded by cataclasis.

The unmixing of perthite into separate albite and potassium feldspar turns out to be a common feature in gneissified per-alkaline rocks: The per-alkaline quartz syenites, syenites and nepheline syenites of Alto Alentejo, Portugal, underwent gneissification in different degrees; they contain perthites in weakly deformed and albite + microcline (or, less commonly, orthoclase) in strongly gneissose types (a.o. de Souza-Brandão, 1902; Osann, 1907; Teixeira & Torre de Assunção, 1957). The umptekite massif of Almunge, Sweden, has a gneissic texture; along its margins orthoclase and microcline + albite are found instead of perthite (Quensel, 1914). A small outcrop of aegirine-riebeckite gneiss containing albite-oligoclase and finely perthitic microcline is present in the Carn Chuinneag orthogneiss complex (Harker, 1962). Fine-grained mosaics of albite and microcline occur around perthites in foliated aegirine-riebeckite granite of NW Angola and W Congo (Holmes, 1915; Mortelmans, 1948). Several occurrences of per-alkaline gneissic granites containing limpid microcline and albite are described by Ducellier (1963) from Upper Volta. Koch (1959) records an isolated occurrence (H. Bollo) of riebeckite gneiss in the Federal Republic of Cameroons. The rock has an equigranular granoblastic texture of quartz, albite and microcline. The aegirine-riebeckite gneisses of Gloggnitz, Austria, are very fine-grained and strongly deformed. It is very difficult to determine the feldspars owing to their fine grain. Zemann (1951) states that microcline and albite occur but not in which state of intergrowth.

Of the thin sections of riebeckite gneiss from Hosséré Bollo, Carn Chuinneag and Gloggnitz, studied by the present author, the former two are strikingly similar to those of the Galiñeiro area. In both rocks microcline is only slightly perthitic; the twinning is very fine and sharp. The Scottish gneiss is more inequigranular than that from Cameroons and therefore resembles more the Galiñeiro gneiss. Plagioclase is exclusively albite in the thin section studied. The Austrian riebeckite gneiss is very different. As remarked above quartz and feldspar form an extremely fine-grained ground mass. Occasionally somewhat larger albites were seen. It is well possible that this different texture is due to the fact that the rock orginally was an extrusive comendite instead of an intrusive per-alkaline granite (Wieseneder, 1965). Nevertheless, it is strongly flattened and if the cataclasis would have been followed by recrystallization of the light-coloured minerals a somewhat coarser-grained, more granoblastic gneiss should have formed.

The synopsis of literature and observations on other rocks, given above, supports the hypothesis that the assemblage microcline + albite in the riebeckite gneiss under discussion is metamorphic. A Rb-Sr age determination on microcline also points to a hercynian age (table 20).

Crystallization of microcline and albite

It seems that the presence of Na-feldspar in solid solution with K-feldspar inhibits the formation of *microcline* because the mixing of Na and K ions encourages disorder of Al, Si atoms (Smith, 1960). The highly ordered structural state of the microcline under discussion was therefore probably promoted by the absence of albite in solid solution. Microcline recrystallized directly as a pure potassium feldspar, because otherwise some perthite should have been present or the mineral should have contained some Na. Another possibility, viz. that a subsequent phase of low-grade metamorphism caused the ultimate recrystallization of albite and microcline is rendered improbable by the fact that not one observation in one of the rocks in the area investigated is indicative of such a phase. As argued above such recrystallization should again have to be preceded by cataclasis.

Because *albite* encloses all other minerals, it is the youngest mineral present in riebeckite gneiss. According to the literature concerning the relation between plagioclase twinning and metamorphic facies (a.o. Turner, 1951; Tobi, 1961) one should have to conclude that the albite in the riebeckite gneisses, with its strong predominance of simple (010) twinning, crystallized under greenschist facies conditions. The facts that at least some complex twins were noted (see ch. III) and that in riebeckite gneiss no other plagioclase than albite can crystallize because of the low Ca content of the rock, might involve that in this case crystallization of the albites described has started during a higher grade of metamorphism.

Many albites contain small grains of fluorite. Patches in some thin sections appeared to consist of fluorite surrounded by large relatively inclusion-free oval albite and by riebeckite. The crystallization of albite (and also of riebeckite!) seems to be influenced therefore by the presence of fluorine in the rock.

Experimental work precisely on the influence of F upon the crystallization temperature of albite during decreasing metamorphism of per-alkaline rock has not been performed as far as the author is aware. Wyllie & Tuttle (1961) found that 'albite crystallized from glass in the presence of HF solutions is several times larger than that crystallized in the presence of H_2O alone'. Furthermore they observed that the melting intervals of albite and granite in "ternary systems" with H_2O and HF were lowered by increase in the amount of HF. In the absence of HF albite begins to melt at about 795° (at 2750 bars pressure), granite at 670°C; when 8 % of HF solution is present, these temperatures are lowered to 610° and 595°C respectively. Althaus & Winkler (1962) experimented with illite, quartz and 3–5 % of a.o. various Na-salts + 10 % H_2O, at pressures of 2kb and temperatures from 230–750°C. Analcime is formed from the original mixture, that at higher temperatures reacts with quartz to form albite, when NaF or NaOH are used. The temperature of the latter reaction depends on the anion present (400°C with NaOH, 300°C with NaF). With other Na-salts the reactions are somewhat different.

Both series of experiments demonstrate that the presence of fluorine indeed influences the size and crystallization temperature of albite.

The albites in riebeckite gneisses from other areas are very similar to those of the Galiñeiro area. They were mentioned by a.o. de Souza-Brandão (1902), Osann (1907) and Zemann (1951) and observed by the author in thin sections of gneisses from localities mentioned above in Cameroons, Scotland and Austria.

Above, the influences from the environment upon the crystallizing albite were discussed. A quite different approach is presented by a.o. Donnay (1940); Gay (1956) and Smith (1958), who argue that the abundance of twin lamellae in plagioclase is influenced by composition, structural state and temperature.

They use the obliquity [1]) of twins as a criterion. According to these authors the twin lamellae are widest in crystals with the highest obliquity; for albites obliquity is at a maximum when a crystal is in its low-temperature state; the frequency of twinning would therefore be lowest in low-albites. The difference in obliquity between high and low structural states is larger in albite than in lime-bearing plagioclase. Mackenzie (1957) states that low-temperature albite is stable below ± 450°C and that above that temperature gradual transitions to the high-T structural state exist, which is stable only above ± 1000°C. Of normal metamorphic albite it is to be expected that it is low-albite, or intermediate but very near low-albite, and that wide twin lamellae occur in them.

The authors mentioned above already indicate some weak points in their concept. The fact that pericline twins are not as abundant as albite twins in certain rocks, for instance, remains unexplained. It is therefore probable that both structural and environmental factors will have assisted in the determination of the habit of albite in the riebeckite gneiss.

The structural control hypothesis, when proved correct, seems to provide good arguments for the occurrence of lamellar twins in albite from riebeckite gneiss where it occurs in contact with two-mica granite (see below).

Dark minerals and accessories

So far, little has been said about the dark minerals. Aegirine-riebeckite and lepidomelane-riebeckite gneisses, both with or without astrophyllite, occur mixed seemingly at random. The assemblage lepidomelane-aegirine was never seen, while riebeckite gneisses containing both lepidomelane and aegirine in more than accessory amounts were not found.

Deformed dark minerals occur only in the two specimens that also carry the cataclastic light-coloured minerals, mentioned above. Predominance of e.g. basal

[1]) The obliquity of the twin is defined as the angle between the true normal to the twin plane and the lattice row quasi-normal to it, i.e. for albite twinning between [010] and the normal to (010) (Gay, 1956).

sections over others in some slides demonstrates that a certain preferred orientation of dark minerals exists in them. Astrophyllite was noted to lie parallel to the foliation (a.o. in 61 Cor. 20, the specimen that provided the astrophyllite for a Rb-Sr age-determination); but it also occurs in a position perpendicular to it (cf. Floor, 1961; fig. 4).

Aegirine surrounding riebeckite in parallel intergrowth was noted more frequently than the reverse. Nevertheless the alteration of aegirine into limonite has proceeded further than that of riebeckite.

Zircon, the commonest accessory, sometimes provides evidence of having grown relatively late. It encloses riebeckite, aegirine, fluorite and pyrochlore in a few cases and was found along a plane oblique to the foliation in a Zorro-type gneiss, without the accompaniment of any other mineral.

Degenhardt (1957) concludes a.o. that amphiboles and pyroxenes, especially the alkaline varieties of the same, are preferred hosts for zirconium. A number of ZrO_2 determinations in alkalic amphiboles and pyroxenes are listed in table 12. Strong variations appear to exist between the ZrO_2 contents within the groups of "igneous" riebeckite and aegirine. The ZrO_2 content of aegirine is generally higher than that of riebeckite.

The present author supposed that ZrO_2 analyses of some of his riebeckites and aegirines might be able to demonstrate whether ZrO_2 was reincorporated into the same minerals during the metamorphic recrystallization or crystallized separately as e.g. zircon. Petrographic arguments in favour of the latter alternative were found in the presence of tiny droplets of zircon in many, if not most, riebeckite gneisses (fig. 10; 75).

The ZrO_2 content of the "metamorphic" aegirine is lower than that of most "igneous" aegirines, though there are two "igneous" aegirines with values in the same range as that of the "metamorphic" aegirine. ZrO_2 of "metamorphic" riebeckite is constantly below .10 %, whereas of the "igneous" minerals it is considerably higher in two of the three analyses quoted (table 12)

Another uncertainty is the influence the ZrO_2 content of the magma exerts upon the zirconium content of aegirine and riebeckite. Besides, if zircon can easily crystallize, it is to be expected that the amphiboles and pyroxenes contain less ZrO_2 than if the crystallization of zircon proceeds with difficulty [1]). As suggested by Gerasimovskii (1941) it is possible that the SiO_2 content of the magma determines whether Zr behaves as a cation (crystallizing as zircon in SiO_2-rich magmas) or as an anion (forming zircono-silicates in SiO_2-poor magmas). It is therefore possible that in SiO_2-undersaturated rocks more ZrO_2 is accommodated in the aegirine and riebeckite or arfvedsonite lattices than in SiO_2-rich rocks. Unfortunately the source rocks of the aegirines used by Washington and Merwin (1927) and Degenhardt (1957) are not given by these authors. Future investigations in order to prove the relation between ZrO_2 in "igneous" and "metamorphic" minerals should be carried out using only samples from per-alkaline rocks with about the same normative quartz contents (or quartz deficiency in the case of undersaturated rocks).

If additional analyses would prove the differences between "igneous" and "metamorphic" minerals to be persistent, the hypothesis that ZrO_2 was excluded from riebeckite and aegirine during their metamorphic recrystallization would gain in

[1]) That this is not always true is proved by the description of Burri (1928) of the per-alkaline syenite-pegmatite of Alter Pedroso, Portugal, in which zircons with diameters of 5 mm are present together with osannite and aegirine, the latter containing 1.84 % of ZrO_2! The fact that this rock, as a pegmatite, is enriched in ZrO_2 might explain this anomaly.

probability. The zirconium, generated in this way, might have been used in the formation of a second generation of zircon (and also astrophyllite?).

The few crystals of apatite found in the thin sections investigated are nearly always surrounded by a rim of a mineral that in a few cases could be optically identified as xenotime. The observed relations between dark minerals and accessories provided the data for the composition of fig. 13.

The major difficulty that arises when one tries to understand their history is that the undeformed habit demonstrates that the dark (and possibly also part of the accessory) minerals recrystallized after the hercynian deformation that caused the foliation. It is impossible to recognize unquestionable relics of pre-hercynian minerals.

Perhaps the riebeckite, aegirine, fluorite and pyrochlore enclosed within zircon belong to such a rarely preserved older generation, but the other possibility, viz. that the minerals are hercynian and were enclosed by a — rare — post-foliation crystallization of zircon is supported by the occurrence of zircons in a plane oblique to the foliation and by the consideration regarding the Zr content of riebeckite and aegirine. Also, aegirine found within xenotime and astrophyllite could be pre-hercynian but this argument is weakened by the possible recognition of two generations of astrophyllite of which one seems pre-hercynian (Rb-Sr age determination, see below) and the other post-foliation (attitude perpendicular to the foliation).

The relations of dark and accessory minerals may not always be well-established, between these and the light-coloured minerals they are even less certain. Nevertheless, hardly any other sequence could be possible than that the dark minerals in the dark-coloured bands and quartz and microcline in the light-coloured bands recrystallized into their present-day habit at about the same time, after the completion of which albite crystallized, mainly in the light bands.

Evidence of late crystallization of riebeckite and accessory minerals can be found in mineralized joints. They are perpendicular to the foliation and appear to contain, in addition to macroscopical riebeckite, concentrations of zircon and xenotime in one thin section.

Stability of riebeckite, aegirine and lepidomelane

As far as the author is aware, the stability relations of aegirine are not yet fully known. Bailey (1963) quenched acmite melts yielding quench-amphibole similar to the synthetic riebeckite-arfvedsonite solid solutions described by Ernst (1962). In contrast with these findings, Milton & Eugster (1959) reported authigenic acmite from the Green River formation, U.S.A., that crystallized at low oxygen pressures as evidenced by the presence of hydrocarbons in the same area.

The experimental work of Ernst (1962) and Eugster & Wones (1962) on the stability relations of riebeckite and riebeckite-arfvedsonite solid solutions and of annite respectively provides very useful data for the understanding of the relations between riebeckite, aegirine and lepidomelane in the Galiñeiro area. As discussed above, these minerals recrystallized after the hercynian deformations and therefore should reflect the P-T-fo_2 conditions of the post-kinematic hercynian metamorphism. Of lepidomelane the only analysis available was unfortunately made on material from a riebeckite-free marginal lepidomelane gneiss. So far, lepidomelane-bearing riebeckite gneisses did not provide enough lepidomelane for another analysis. As argued in chapter III the analyzed lepidomelane has a composition between that of most lepidomelanes and the theoretical end-member annite (table 8, fig. 17). The refractive index γ (1.674) is also intermediate between those of lepidomelane (around 1.66) and of synthetic annite (about 1.694). Riebeckite (cf. analysis, table 3) is poor in arfvedsonite molecule as indicated by its quantity of Na+K+Ca (210). Since the aegirine turned out to be very pure (table 5), the natural minerals of the Galiñeiro area have compositions near the synthetic ones investigated by Ernst, Eugster & Wones.

Nevertheless, the natural systems of the various types of riebeckite gneiss are much more complex than the experimental ones: the fluid is not purely hydrous but will have contained e.g. some fluor; Fe^{2+} is partly replaced by Mg; alumina is present, though in comparatively small amounts; lithium is a not unimportant constituent of both riebeckite (see section petrochemistry, chapter III) and lepidomelane. Moreover, other FeO-bearing minerals (astrophyllite for instance) may have exerted their influence upon the Fe^{3+}/Fe^{2+} ratios in riebeckite and lepidomelane.

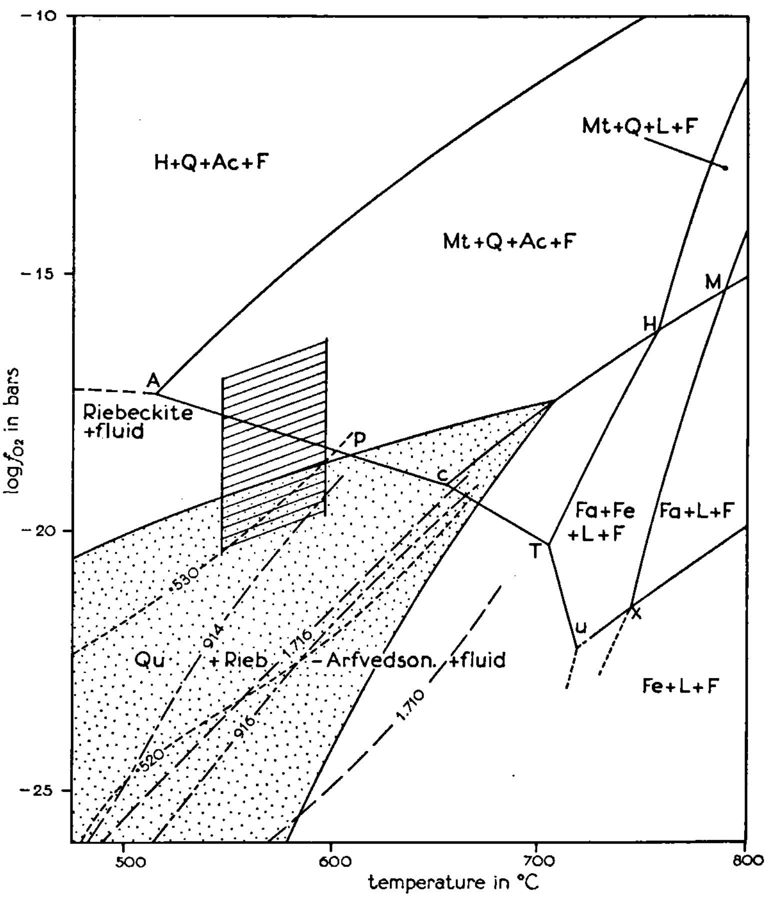


Fig. 52 Stability relations of riebeckite and riebeckite-arfvedsonite solid solutions (after Ernst, 1962) and of annite + quartz (dotted; after Eugster & Wones, 1962). Explanation in text.

The properties of the latter minerals clearly reflect the differences between natural and synthetic minerals. The silicon proportion of riebeckite 61 Cor. 20 (table 3) is .530, which places the mineral near riebeckite in the experimental fo_2-T diagram (Ernst, 1962; fig. 5). The refractive index γ (1.706, table 3) and cell volume (916 Å^3, table 4), however, suggest much lower fo_2 values when compared with the data on figs. 2 and 4 of Ernst (1962). His table 9 provides optical data of synthetic and natural riebeckites and arfvedsonite. The values of α and γ of the Galician riebeckite agree well with those of the natural riebeckite (crocidolite; from Kliphuis, South Africa: α : 1.698; γ: 1.706) quoted by him from Peacock (1928). Since the latter author does not list the F-contents of the analyzed crocidolites, it does not seem warranted to state that the lower refractive indices of natural material resulted from substitution of Fe^{2+} by Mg (Ernst, 1962; p. 697). Borley (1963) underlines the influence that F and Li exert upon the refractive indices of alkaline amphiboles. Ernst could not compare cell volumes of natural and synthetic riebeckites because of lack of data on natural minerals. The cell volume of nearly pure riebeckite from Shetland, calculated from data of Phemister et al. (1950), by Ernst (1962; p. 731) turned out to be 916 $Å^3$, like that of riebeckite 61 Cor. 20 and therefore in the range of synthetic riebeckite-arfvedsonite solid solutions (Ernst, 1962; fig. 4). In the author's opinion it is therefore not impossible that the cell dimensions of natural riebeckites will turn out to be somewhat larger than those of their synthetic analogues.

Since fayalite is absent and hematite was seen in a special case only, the assemblage is unbuffered to changes in fo_2 by reactions involving these common buffer minerals; it is difficult to ascertain, however, whether hidden buffers are present in the natural riebeckite gneiss system. In the reasoning following below it will be assumed that such buffers do not exist.

In figure 52 the stability field of annite in the presence of quartz (Eugster & Wones, 1962) is incorporated in the isobaric fo_2-T diagram for bulk composition $Na_2O.5FeO_X.8SiO_2+$ water (Ernst, 1962) both at 2000 bars P_{fluid}. The univariant equilibrium curves of annite and riebeckite (riebeckite-arfvedsonite), projected on the P-T plane are nearly vertical. Relations similar to those illustrated in fig. 52 should therefore exist at higher pressures, high-temperature limits being raised slightly (Ernst, 1962; p. 731). Presence in the fluid of other components than those in equilibrium with pure riebeckite (mostly H_2O) reduces the temperature of its high-temperature stability limit. On the other hand stability is increased again by replacement of Fe^{2+} by Mg and of OH by F (Ernst, 1962). The numerical values in the diagram presented should therefore be handled with caution!

The experimental values of γ, cell volume and silicon proportion, discussed above, are also indicated in fig. 52. As argued above the Galiñeiro riebeckite has probably formed under conditions nearer to those of riebeckite than would appear from simple plotting of determined γ and cell volume in the diagram, viz. at somewhat lower temperature and higher oxygen fugacity. This is also the case because aegirine-lepidomelane assemblages are absent, so that the temperature cannot have been much higher than that of the low-temperature intersection P of the annite + quartz stability field and the curve ACT (fig. 52). On the other hand, the absence of hematite conditions that the temperature was higher than the one corresponding to the point A in a natural system. Since the finding of authigenic acmite suggests that the stability field of aegirine extends below the univariant curve ACT, crystallization of the riebeckite gneiss assemblage will have proceeded under fo_2-T conditions defined by points somewhere in the hatched area in fig. 52. Small variations in the chemical potentials of potassium and, to a lesser extent, of alumina, seem to have led to the crystallization of lepidomelane in some types, under conditions falling within the stability field of that mineral. Above the high oxygen fugacity limit of the annite stability field potassium feldspar + quartz + magnetite + vapour can form (Eugster & Wones, 1962; fig. 6). When fo_2-T conditions surpass the stability limit of riebeckite + riebeckite-arfvedsonite, only aegirine and magnetite can form. This probably was the case at the end of the metamorphic recrystallization when riebeckite was occasionally surrounded by aegirine.

The fo_2-T conditions that were deduced from the observed parageneses are normal for the hercynian metamorphism: According to Eugster & Wones (1962) oxygen fugacities within the earth's crust are generally within the stability field of magnetite, while temperatures between 500° and 600° C and pressures between 2 and 5 kb appear to define the andalusite-(staurolite)-cordierite subfacies of the amphibolite facies (den Tex, 1965; fig. 6).

Optical properties of riebeckite from gneiss, joints and pegmatites were not yet compared in detail. Their X-ray powder patterns, however, are fully identical.

Marginal types of riebeckite gneiss

Marginal types of riebeckite gneiss contain assemblages of dark (and sometimes accessory) minerals distinct from those in the "normal" riebeckite gneiss, while the light minerals resemble those of the "Galiñeiro type". Mostly the dark minerals are less extremely alkaline, aegirine-augite occurring instead of aegirine and green amphibole instead of blue. Brown biotite is occasionally taking the place of very dark brown to nearly opaque lepidomelane. Titanite is more common; plagioclase somewhat more basic than pure albite was noted in specimens collected near contacts with neighbouring paragneiss.

Magnetite gneiss with tiny grains of riebeckite, aegirine or lepidomelane only enclosed within albite show extensive development against amphibole-biotite gneiss on the NE slope of Monte Galiñeiro. The transition into the normal riebeckite gneiss of Sierra de Galiñeiro is gradual. Magnetite gneisses were also described from Alter Pedroso, Portugal (Burri, 1928) and Gloggnitz (Keyserling, 1903).

The formation of magnetite instead of riebeckite cannot be due to a raise in oxygen fugacity since this would involve simultaneous crystallization of aegirine (see fig. 52). Evidence is abundantly present that metasomatic transport of sodium, a little zirconium and possibly also potassium and titanium took place in the direction of the surrounding rocks: The albite that crystallized as a result of this metasomatism in adjacent rocks is clearly post-tectonic and the "export" of sodium must therefore have taken place during or after the hercynian deformation, that is: when the two phases of the original perthite had completely separated. The group of amphibole-biotite rocks and associated gneisses seems to provide arguments for the additional existence of pre-hercynian metasomatism as will be discussed in the section dealing with these rocks. Vestiges of sodium, potassium, zirconium and titanium metasomatism will also be mentioned when describing the paragneisses in which they occur.

It must be concluded therefore that most marginal facies owe their formation to interactions between per-alkaline granite resp. gneiss and wall rock both before and during the hercynian orogeny, but it remains obscure which changes took place at which moment. Some marginal types (see chapter III) are probably differentiation products of the per-alkaline granite and will be mentioned below.

Dilatation pegmatites

The occurrence of undeformed dilatation pegmatites carrying microcline, quartz, albite, apatite and occasionally riebeckite, astrophyllite, aegirine, especially in the narrower ones, is difficult to explain. If they were generated within the riebeckite gneiss complex they should have formed by anatexis at a much deeper level than that exposed now, since anatectic phenomena are absolutely absent in the outcrops studied. The shape of the complex suggests, however, that its floor will not be very deep below the surface. An origin through anatexis of riebeckite gneiss is therefore highly improbable. A striking fact is the occurrence of numerous pegmatites connected with the two-mica granites e v e r y w h e r e a r o u n d the riebeckite gneiss arc, and — on the other hand — t h e a b s e n c e o f s a m e within that arc. Dilatation pegmatites in the amphibole-biotite rock and gneiss complex consist of microcline, quartz, albite, apatite and a few flakes or grains of mica resp. tourmaline. Since it is equally impossible to explain the generation of these pegmatites by anatexis, the only explanation the author can envisage is that they represent two-mica granite pegmatites as present outside the arc, but modified by interaction with the riebeckite or amphibole-biotite gneisses. The presence of large amounts of apatite, rare in riebeckite gneiss, and of grains of tourmaline absent both in riebeckite gneiss and in amphibole-biotite rocks and gneiss support this theory, as does the increase of riebeckite, etc. contents in narrower veins.

Contacts with two-mica granites

A completely distinct kind of interaction between riebeckite gneiss and adjacent rock is that between riebeckite gneiss and two-mica granite intrusive into it, exposed along the shore of La Guia and on the N and E slopes of San Bartolomé and Cepudo. Riebeckite and aegirine were altered into very dark brown biotite near the contacts. Replacive relations between albite and microcline, very rare in "normal" riebeckite gneiss, were generally noted in the contact aureoles. Albite has very narrow polysynthetic albite twins instead of simple ones.

The structural control concept of a.o. Donnay, Gay and Smith, mentioned above, may assist in understanding this different behaviour when proved correct by careful investigation of more natural and synthetic albite. The intruding two-mica granites heated the minerals of surrounding rocks somewhat above the temperatures of their metamorphic formation [1]). In albite this would have caused a transition to a structural state, intermediate between that of low- and high-albite, corresponding to the higher temperature. This would result in a lower obliquity of the twins which consequently show narrower lamellae. Gay (1956) states (pp. 304–305): 'calculations for heated and partially inverted specimens in the An_0 to An_{15-20} region suggest that the obliquity can fall to values that are appreciably less than those for the synthetic specimens in this region. It may be, therefore, that in this composition range the finest albite twinning can be developed by feldspars in an intermediate structural state'. It is possible, however, that the data quoted cannot be applied literally to heated natural low-albite.

In a sample collected a few metres from the contact and still carrying riebeckite, microcline is the youngest mineral. Since this is normally not the case it may point to the metasomatic introduction of some potassium into the gneiss.

At La Guia, contacts are sharp. In the granite, xenoliths of altered riebeckite gneiss are rare, of paragneiss very frequent. It is therefore probable, that the granite did not penetrate very far into the riebeckite gneiss. Up to about 20 cm from the contact the granite carries biotite only. Micrographic intergrowths of microcline and quartz are not rare. Biotite pegmatite, a few cm thick, was found locally between granite and gneiss.

Instead of a sharp contact a nebulitic planar biotite gneiss is present at several places on the slopes of San Bartolomé and Cepudo. Fresh outcrops are much rarer than along the coast. Replacive relations between albite and microcline, though present in less modified contact-metamorphic riebeckite gneisses were not seen in these rocks. On the ground of their occurrence near and in the continuation of contact-altered riebeckite gneiss the nebulitic gneisses are thought to represent riebeckite gneisses that were partly mobilized or assimilated by the intruding two-mica granite. Since a biotite gneiss resembling that on the NE slopes of Cepudo and San Bartolomé was found further south along the contact between coarse-grained inequigranular and medium-grained inequigranular two-mica granite, it seems that, as at la Guia, the riebeckite gneiss was also here more resistant to the intruding granites than the adjacent paragneisses.

Remarkable is the fact that riebeckite gneiss of the Sierra de Galiñeiro is

[1]) Clark (1964) described the geothermometry of a mineralized hercynian granite near Panasqueira, central Portugal. Arsenopyrite in high-temperature deposits yielded a crystallization temperature of 610 ± 20°C.
Crystallization of the granite should have taken place at higher temperatures. Clark does not describe the granite exactly. The fact that it contains albite (An_{5-10}) and muscovite suggests that it belongs to the group of two-mica granites.

separated everywhere by a narrow band of paragneiss from the coarse-grained equigranular two-mica granite to the SW.

Pre-hercynian aspects of the per-alkaline rocks

Complete recrystallization during the hercynian orogeny renders a description of the pre-hercynian history of the per-alkaline rocks highly speculative, while the metasomatic removal of sodium, and some potassium, zirconium and titanium (described in subsequent sections) may partly have caused the appearance of marginal facies whereas others may be original.

Since the riebeckite gneisses do not contain amphibolite lenses, such as are abundantly present in orthogneiss and paragneiss, emplacement of the original per-alkaline rock should have taken place after that of the basic rocks and should therefore necessarily be of an igneous nature. If it had been extrusive it should have had about the same age as the paragneisses and should have to contain amphibolite lenses; it cannot be younger because in that case it should have to rest uncomformably upon part of the metasedimentary series.

In consequence, it is an intrusive rock, though it cannot be stated without doubt whether it intruded as hypabyssal granitic dykes or as a more deep-seated granite. The generally rather large size of zircon and astrophyllite that might at least partially be minerals of the original intrusive rock, seems to indicate that it was not fine-grained, i.e. that it probably had a granitic texture. In the following paragraphs will be written about "riebeckite granites" in the assumption that the plutonic character is fully established.

It has been pointed out already that per-alkaline granites described in the literature always contain perthite as a primary feldspar. In other words, they are one-feldspar or hypersolvusgranites (Tuttle & Bowen, 1958; p. 129). Smith (1960) demonstrated that the presence of anorthite and volatile constituents both raise the solvus in the feldspar system, in certain cases even until it intersects the solidus of the system, resulting in separate crystallization of plagioclase and potassium feldspar, directly from the melt. Because Ca is very low in per-alkaline granite and the water-vapour pressure was low during its crystallization, solvus and solidus did not intersect, resulting in the crystallization of one feldspar. The existence of low water-vapour pressures can be deduced from the fact that the granites often carry Na Fe-amphiboles, which are only stable at low P_{H_2O}. This also explains the absence of marked contact-metamorphism and of large zoned pegmatites (e.g. Raulais, 1960). As argued by Tuttle & Bowen (1958) unmixing and recrystallization of feldspars are greatly accelerated by the presence of water-vapour under pressure. The low P_{H_2O} may therefore have prevented large-scale unmixing in per-alkaline granites. The feldspars will have exsolved into perthites with sometimes some secondary albite around them but complete separation into albite and potassium feldspar did not occur.

The texture of the granite now present as Zorro-type riebeckite gneiss probably was somewhat coarser-grained or porphyritic compared with the granite that yielded Galiñeiro-type gneiss, as seems to follow from the coarser grain of microcline in Zorro-type gneiss.

Compared with the riebeckite in the gneisses of the area under discussion, the alkali amphibole in the original granite should have had a somewhat different composition. Ernst (1962) made it clear that pure hydroxyl riebeckite is unstable at magmatic temperatures. Natural igneous "riebeckites" always have their vacant position partly filled with (Na, K, Ca) indicating that they are riebeckite-arfvedsonite solid solutions (Ernst, 1962; Borley, 1962; Fabriès & Rocci, 1965), which are stable at higher temperatures but lower oxygen fugacities. The isotopic age determination of astrophyllite (table 20), when not completely in error, proves that some astrophyllite is an original constituent. Part of the accessory minerals will probably also be minerals of the original granite, but there are few arguments to substantiate this.

The age-relations between the various types of riebeckite and related gneiss could not be established. The occurrence of fine-grained bands within Zorro-type riebeckite gneiss (fig. 14) proves that this gneiss is older than the bands, which have the composition of Galiñeiro-type riebeckite gneiss. Since the texture of the bands is distinct from that of Galiñeiro-type gneiss, however, the age relations between the two types of "normal" riebeckite gneiss cannot be deduced unambiguously from this observation alone.

It would be very interesting to know whether the actual strong variation in dark mineral content is due to locally differing physico-chemical circumstances during metamorphism or to original variations in chemical composition that were thoroughly "mixed" by the hercynian cleavage-folding generating the foliation. Many more rock and mineral analyses will have to be made to warrant any conclusion regarding this uncertainty.

The few xenoliths found in riebeckite gneiss are enriched in microcline, but it could not be established when this happened (cp. the paragraphs regarding potassium metasomatism in the sections about paragneiss and amphibole-biotite rocks and gneisses further below).

The radioactive gneiss, rich in allanite, xenotime and zircon is considered to be a peculiar differentation product of the per-alkaline magma. It has the same light-coloured mineral constitution (much quartz and albite, little microcline) as "microcline-poor quartz-albite rocks" occurring marginally within and around "leucocratic planar gneiss" and as a dyke-like intrusion somewhat more to the south. (All these rocks will be mentioned when describing the amphibole-biotite rocks and associated gneisses). E of Zamanes the rock occupies an isolated place among paragneiss (fig. 15); N of Zamanes its relation with riebeckite gneiss is very clear.

It is possible that magnetite-zircon gneiss found near radioactive gneiss N of Zamanes is also an unusual differentiation product. Because magnetite as a major constituent is elsewhere restricted to marginal types some modification by metasomatic transport of sodium from per-alkaline rock into adjacent paragneiss might have assisted in bringing about its actual appearance.

Pegmatites and quartz veins are partly pre-hercynian, since they were deformed by the hercynian movements (fig. 16). Old pegmatites are rare, but, as stated above, this is a common property of per-alkaline granites, caused by their low water content.

Some of the Portuguese per-alkaline gneisses are intrusive into Upper Cambrian limestones. Gabbros were intruded by the per-alkaline syenitic rocks but are themselves also intrusive into the Upper Cambrian limestones. Both rocks must therefore have a Silurian [1]) or younger age. An upper limit is set by the hercynian orogeny causing the foliation of the gneisses. Teixeira & Torre de Assunção (1957) place the intrusion of the syenites between Silurian and Upper Westphalian.

Rb-Sr age determinations on whole rock and astrophyllite (61 Cor. 20, table 20) yielded average ages of 486 and 544 m.y., i.e.: Lower Ordovician and Middle Cambrian respectively (Geol. Soc. Phanerozoic time- scale, 1964). Riebeckite gneiss,

[1]) Teixeira and Torre de Assunção (1957) subdivide the Silurian into Ordovician and Gotlandian. In this paper, the division made in e.g. Geol. Soc. Phanerozoic Time Scale (1964), which recognizes Ordovician and Silurian as systems, is used.

however, cannot be older than 500 m.y. (see section northeastern orthogneiss complex, below, and also Priem et al., 1966).
As remarked above, the fact that the astrophyllite of 61 Cor. 20 has been dated as pre-hercynian is either an exception or an error; undeformed astrophyllites with random orientations and therefore post-kinematic are seen in most rocks. Yet, even this astrophyllite is enclosed by riebeckite and aegirine and does therefore not constitute a very young mineral of the second generation (cp. fig. 13).

THE AMPHIBOLITES

Very dark and fine-grained lenses or irregular bodies of amphibolite, mainly found within the NE orthogneiss complex or in paragneiss surrounding it, have a relictic micro-porphyritic structure in common (fig. 27). They are therefore considered to have an igneous origin, i.e., they are ortho-amphibolites. As to their relative age, one could maintain that they are present in the orthogneisses as xenoliths, as they are in the megacrystal granites. But their distribution in paragneiss only in the vicinity of orthogneiss proves that their presence is more than haphazard. The ortho-amphibolites are probably genetically related with the orthogneisses and intrusive into them and the surrounding metasediments. They are intermediate in age between riebeckite gneiss and amphibole-biotite rock and gneiss, which do not, and those varieties of orthogneiss that do contain amphibolites. Taking their dioritic composition (table 16) into account they were microdiorite porphyrites before the hercynian orogeny.

Three amphibolites, consisting like the afore-mentioned ones of fine-grained plagioclase aggregates, green hornblende and accessories (table 14), show a blastophytic structure in thin section (fig. 28). All three were collected along the road Vincios-Porriño in the vicinity of Zamanes and probably represent metamorphosed dolerite dykes.

Remarkable is the fact that the porphyritic and ophytic structures remained so well preserved during the hercynian orogeny. Preferred orientation of hornblende or foliation (when present parallel to the foliation of adjacent gneiss) are rare. While in the surrounding rocks the penetrative deformation acted strongly, the basic dykes were apparently competent bodies, in most cases yielding by boudinage. The irregular and folded bodies observed in good exposures (fig. 26) must have undergone at least some deformation.
The constituent minerals of the dykes adapted themselves to the metamorphic conditions by recrystallization. Plagioclase phenocrysts recrystallized into aggregates of tiny grains with subparallel orientations and variable anorthite contents, dark minerals into green amphibole and small amounts of biotite.

A third group of amphibolites has no specific characteristics. Unlike the preceding amphibolite types, they generally contain quartz. Their textures are too modified by metamorphism than that a sedimentary or igneous origin could be assigned to them with certainty.

The fourth group shows so many textural similarities with metablastic paragneisses that it will be described together with them.

THE NORTHEASTERN ORTHOGNEISS COMPLEX

Like the riebeckite gneisses the many types of biotite gneiss together constituting the northeastern orthogneiss complex show arrangements of dark minerals indicative of strong deformation. They are planar (of exactly the same texture as riebeckite

gneiss), linear or planolinear through the arrangement of their dark minerals in planes, rods or by a combination of these two structures. Linear or planolinear rocks are mostly coarser-grained than planar gneisses.
The foliation was caused by the hercynian orogeny, as can be deduced from Rb-Sr age determinations (see below).
Folded foliation was never observed in the field. Large-scale structures have been constructed from individual measurements of dip and strike and are represented on the geological map (plate 1). N-S folds are the most important structures, some of them have been arched around an E-W axis (e.g. the "Lonsa dome").
The rather isolated body of so-called "Mosende gneiss", in the SE quarter of the map has ill-defined contours, because of its cover by vegetation and recent sedimentary deposits. The same kind of flexure seems to be present as in the eastern band of riebeckite gneiss, more to the NW. Foliation of this rock is difficult to measure since it is less pronounced than that of the gneisses in the NE part of the map due partly to the scarcity of biotite.
Changes in texture are too frequent for delineation on the map of types that have macroscopical or microscopical characteristics in common.

Macroscopical and microscopical aspects

The presence or absence of feldspar augen (often with Carlsbad twins) and the planar or planolinear texture of the rocks served as criteria for a *macroscopical subdivision* (fig. 35).

The *microscopical subdivision* has been based upon the habit and distribution of quartz. The feldspar augen are composed of microcline, not rarely enclosing tiny hypidiomorphic plagioclases with a distribution resembling that in phenocrysts of porphyritic granites: parallel to the outlines of the host. The surrounding quartz-feldspar aggregates are normally much finer-grained than the augen.
Irregular bands of rather coarse grains of quartz define type I (fig. 36a, b). In type II quartz crystals are smaller, have an elongated shape and were found as more or less continuous "trains" or as separate individuals (fig. 37a, b).
The feldspar aggregates between the quartz often show subparallel extinction of adjacent grains when inspected with the quartz comparator. Implication intergrowth of plagioclase, microcline and some quartz is common, mosaic structure rare. Anorthite contents of plagioclase are variable (cp. table 17, fig. 31). In some rocks albite is the only plagioclase present and such rocks resemble the "leucocratic planar gneisses" cropping out E of Zamanes. A direct relation between content of porphyroblastic albite and distance from riebeckite gneiss as observed in paragneiss does not exist. Plagioclase was noted to replace microcline and conversely.
The biotite of the bands or rods appears to be completely undeformed, often even unoriented. In a few cases biotite and amphibole were found occurring together (fig. 33) but more often green amphibole was noted preferentially as poeciloblasts in the feldspathic aggregates (fig. 32). The composition of amphibole is controlled by the chemistry of the rock in which it occurs as can be deduced from the variability of the measured optic axial angles: $2V_{\alpha} \pm 60°$ and max. 35° respectively in two specimens from one quarry. Small optic axial angles of dark green amphiboles point to a high content of the ferrohastingsite molecule in them.
As was the case with riebeckite gneiss, one often doubts whether minerals are primary or recrystallization products. This mainly applies to the accessories but also to muscovite, which is a major constituent in a few specimens only. When present, however, flakes are nearly always bent which is in striking contrast with the habit of biotite. This different behaviour should probably be ascribed to the fact that

biotite could alter into chlorite during mylonitization and recrystallize into undeformed biotite in the subsequent period of metamorphism.
Interesting accessories are: titanite, with comparatively large optic axial angles (up to 50°, indicative of a high rare-earth content), xenotime (as a rule not together with apatite, table 17), allanite (large undeformed idiomorphic crystals in a considerable number of rocks: fig. 33) and fluorite. Zircons are often turbid; hypidiomorphic and idiomorphic outlines predominate over rounded ones. The zircons in Mosende gneiss resemble those from riebeckite gneiss.

The textures of the rocks demonstrate that they underwent mylonitization causing the foliation and recrystallized subsequently; they are now blastomylonites. Differences in texture probably depend partly upon differences in grainsize of the pre-hercynian rocks: augengneisses were porphyritic granites. The presence of flow-structures in some and their absence in other rocks may also have played a role. Finally there may have been differences in the moment of cessation of hercynian penetrative movements with regard to recrystallization.
The fabric of the gneisses is very similar to that of leucocratic orthogneisses from the Black Forest described by Mehnert (1940). Paragneisses in that area are strongly metablastic, orthogneisses less clearly so. The same is the case in the author's area. Metablastic crystallization will receive attention in the next section (paragneisses).

Many roof pendants, septa or xenoliths of orthogneiss are found in megacrystal granite. The aspect of these orthogneisses is somewhat different from that of the eastern rocks. Two groups were distinguished: IA resembles I but has coarser feldspar aggregates (fig. 36c); IIA has equidimensional instead of elongate quartz grains (fig. 37c). Macroscopical differences between rocks of groups I and IA and between II and IIA are scarce. The rocks in contact with granite have an a little more sugary appearance; biotite is somewhat less concentrated. In the author's opinion these differences are caused by a thermometamorphic recrystallization oj normal orthogneisses. It is remarkable that such effects are hardly visible where orthogneiss is in contact with cordierite-quartzdiorite which is intrusive into the eastern part of the complex.

As argued in the preceding section the shapes and textures of many enclosed amphibolite bodies demonstrate that a large part of the penetrative movements in the gneisses by-passed the amphibolites.
Aplites are seen here and there in orthogneiss. They have a foliation parallel with that of the gneiss. Quartz veins are sometimes shear-folded, likewise presenting evidence of their pre-hercynian origin.

Origin of the orthogneisses

Many arguments speak in favour of the igneous origin of the gneisses under discussion. One of the strongest is the presence of rocks considered to be hornfelses at several localities around the gneiss. They will be mentioned in the section concerning the paragneisses.
Reviewing the pre-hercynian history of the orthogneisses one arrives at the concept of a varied sequence of biotite, amphibole-biotite and biotite-muscovite granites to granodiorites intrusive into each other. In contrast with the riebeckite gneisses, of which textures and compositions of albite and microcline indicate that they originally were one-feldspar or hypersolvus granites, the properties of the feldspars of most northeastern orthogneisses suggest that they were subsolvus or two-feldspar granites (Tuttle & Bowen, 1958; p. 129).
The "Mosende gneiss" does not contain enclosed amphibolite lenses. Perhaps some

types of the main body are also free of them. Since no separate petrographical types could be mapped, the distinction between amphibolite-carrying and -free gneisses was impossible to make.
After the emplacement of a number of granites the intrusion of the basic dykes must have taken place, followed by that of a few more granitic rocks. The paragneisses enclosed in a N-S trending zone with steep dips, in the centre of the main gneiss body, are probably tectonic inclusions and not xenoliths. As far as could be ascertained now the whole complex was poor in pegmatites.

Rb-Sr age determinations were made of whole rock and biotite from an orthogneiss from the W slope of Monte de Rebullón (situated W of Puxeiros; table 20). Biotite yields the age of the latest hercynian recrystallization in the area, whereas the whole rock has the age of the base of the Ordovician. (Geol. Soc. Phanerozoic time-scale, 1964).
When the data on this gneiss are compared with those of riebeckite gneiss it should be remembered that petrographic evidence places the latter younger in age than the former, both being separated by the intrusion of the basic dykes.

Since the lack of major tectonic unconformities in the Lower Paleozoic sequence precludes the action of the caledonian orogeny in NW Spain (Stille, 1927) the isotopic ages provide further proof that the riebeckite and other orthogneisses were foliated by the hercynian orogeny.

THE PARAGNEISSES

Presenting a comprehensive survey of the complex history of the metasedimentary rocks is no easy task. It will be necessary to proceed in several steps: The hercynian processes in what are now normal muscovite-bearing biotite-plagioclase gneisses, para-amphibolites and cordierite-bearing Pereiras-type gneisses will be described first. A subsequent part deals with Lonsa-type gneisses and the typical fine-grained and -banded appearance that characterizes many specimens, followed by a discussion of the pre-hercynian history of all paragneisses. Finally, the changes that resulted from the intrusions of hercynian granites and the influence of riebeckite gneiss and granite upon adjacent paragneiss will pass in review.

Normal paragneisses

Biotite-plagioclase gneisses considered as "normal" paragneisses present an immense diversity in themselves. In most cases plagioclases (with diameters of over 5 mm in coarse-grained varieties) are well visible giving the rock the aspect of dark-coloured fine-grained spotted gneisses (fig. 40).
The plagioclases often enclose quartz and mica. Around the plagioclases the rocks are mostly made up of quartz and mica (always biotite, muscovite strongly variable and not rarely absent). The quantities of quartz and mica themselves may also vary. When scarce the plagioclases are in contact with each other; when abundant they lie in a quartz-mica mass. Biotite is often present as rather large unbent crystals (especially when compared with biotite in plagioclase). Their orientation is either parallel to the schistosity of the rocks s_e, or unoriented, or oriented mainly oblique to s_e ("cross-biotite"). In the latter two cases the schistosity is brought about by planar parallelism of muscovites or inconspicuous. Inconspicuous schistisities are especially common in plagioclase-rich, quartz- and mica-poor rocks. A few grains of andalusite were occasionally recorded. They were seen to enclose the large biotites mentioned above, but in other specimens this relation is not clear. The andalusite is therefore considered to be contemporaneous with or slightly younger

than coarse biotite. Coarse quartz is also younger than the finer crystals of the same mineral enclosed within plagioclase; it is elongated parallel with s_e or equidimensional. "Trains" of quartz crystals parallel to s_e were noted.

The parallelism of biotite and quartz with the schistosity in some rocks and the absence of the same in others were probably determined by the relation between deformation and crystallization that varied from place to place (and depended also on the composition of the rocks). s_e was never observed enclosed within plagioclase. Mehnert (1957) in his decription of Black Forest paragneisses introduced the term "Zwickelquarze" for the quartz outside the plagioclases and the process of crystallization of rather coarse quartz and biotite he referred to as "Sammelkristallisation".

As to the plagioclases themselves, they are usually composed uniformly of polysynthetically twinned oligoclase or acid andesine. As remarked above, they enclose many minerals: accessories, muscovite (rare), garnet (nearly always resorbed and turbid (fig. 39) but in the majority of observations without accompanying alteration products, thus proving that they were already resorbed when they were enclosed by plagioclase), biotite (often flakes parallel per plagioclase host-crystal) and quartz (figs. 38, 39, 41). This mineral is present as tiny droplets with parallel orientations in groups or even in single plagioclase crystals and as larger but also small crystals with varying extinctions. The content of these quartz crystals is variable. They are less common especially in plagioclases of mica-rich bands or specimens, and elongate or equidimensional. When elongate, they proved to have preferred dimensional orientation per plagioclase host (fig. 39); biotite flakes, when present, generally have a similar orientation. This parallelism of enclosed minerals gives evidence of an inclusion-fabric (s_i).

Quartz enclosed within plagioclase gives important information about the structures that existed before the plagioclase crystallized. All possible relations between s_i and s_e were observed: s_e present, s_i present; *se* present, s_i absent (equidimensional quartz, no biotite flakes enclosed) and s_i present or absent in the absence of s_e. When in rocks with plagioclases containing s_i the directions of the individual s_i are compared with each other, it appears that these individual s_i are not always parallel. Either the individual plagioclases were rotated during the formation of s_e or they enclose a so-called helycitic s_i fabric (fig. 48). In the latter case some rotation of individual plagioclases certainly also took place.

No strong preferences of certain types of enclosed quartz appear to exist for certain areas. Plagioclase enclosing elongate quartz is a little more common outside than within zones adjacent to riebeckite and NE orthogneiss. (There is, however, also a preference for elongated quartz grains in quartz-rich rocks, see below). Fine-grained biotite gneiss containing some microcline was found in a zone between Filgueiras, S of the riebeckite gneiss, and N of Zamanes.

The large plagioclases described in the preceding paragraphs have apparently grown selectively at the expense of other crystals because they enclose old structures. The process that facilitated their growth has the characteristics of m e t a b l a s t- e s i s (= 1: Recrystallization and growth of a preferred mineral or mineral group; 2: Essentially isochemical recrystallization (with no evidence for the existence of a separate mobile phase); Dietrich & Mehnert, 1960; p. 64). The plagioclases are metablasts and very similar to those described by Mehnert (1957) from the Black Forest. Mehnert's metablasts do not contain the parallel-extinguishing quartz droplets present in the Spanish plagioclases. The grains that are called "quartz crystals" in this paper are "Tropfenquarze" in Mehnert's nomenclature. The presence of elongate quartz crystals in metablasts from quartz-rich rocks was also noticed by Mehnert.

Paragneisses are often banded. Recumbent isoclinal folds (axes roughly meridional and horizontal) with amplitudes of about one metre are not rare. Often they are not real folds but piles of lenses derived from bands with more quartzo-feldspathic compositions (and consequently behaving more or less competently) separated by mica-rich planes on which the differential movement was concentrated. Large-scale structures were constructed in the map (plate 1) from individual measurements and should be regarded with some reserve. The schistosity s_e proved to lie parallel to the axial plane of folded banding (biotite parallel s_e); in unfolded banded rocks s_e is not always parallel to the banded structure. Microfolded s_e was locally observed in outcrops.

It is very difficult to link metamorphic recrystallization processes with hercynian deformation. Since plagioclase metablasts never enclose s_e they did not grow after its formation. Like the amphibolites, the mica-poor paragneisses without s_e must have been comparatively competent. Probably the same process as in amphibolite lenses took place: recrystallization without foliation, the movements having been concentrated along their margins or along a small number of discrete planes in these rocks. The metablasts are either equidimensional or oval; in the latter case they must have grown partly during the deformation of the rocks, between the mica-rich planes along which most of the movement took place. Biotite outside the metablasts has partly recrystallized after the penetrative movements (non-bent crystals often unoriented or oblique to s_e), muscovite has also recrystallized but remained parallel to s_e. It will be necessary to know the description of the Lonsa-type gneisses before the history of s_i can be further discussed.

Para-amphibolites

In chapter VII a cummingtonite-biotite-garnet-bearing quartz-bytownite rock was described. In specimen this peculiar rock is hardly distinguishable from normal paragneiss. Only under the microscope did the completely distinct mineralogical composition become apparent. Quartz is present as small crystals in bytownite metablasts in the same way as it was described in oligoclase from the normal paragneisses.

Bytownites enclosing the same type of quartz, only both minerals of somewhat smaller dimensions, were found in the fourth type of amphibolite (fig. 29). These rocks are further composed of green hornblende (mostly very light-coloured), colourless cummingtonitic amphibole, some biotite, apatite, ore and titanite. One specimen partly consists of an equigranular mosaic of quartz and bytownite grains, and partly of metablastic bytownite enclosing small quartz. Cummingtonite is unoriented, whereas the light green amphiboles are not rarely of parallel orientation. The former mineral generally surrounds, but also cuts the latter (fig. 30): it is a constituent of late crystallization (about contemporeous with biotite and andalusite in the normal paragneiss) while the green amphibole is older.

Because of the striking similarity of their metablastic bytownites with the oligoclase metablasts of normal paragneisses, the bytownite-bearing rock types are considered to have a sedimentary origin. The amphibolites are thus para-amphibolites.

Para-amphibolites — when outcropping — were always seen as lenses or boudins; when foliation is present it is parallel to the schistosity in surrounding paragneiss. A chemical analysis of para-amphibolite is given in table 16.

Pereiras-type cordierite gneiss

Gneisses of the Pereiras-type contain isolated crystals or nodules of cordierite in metablastic paragneiss (fig. 42). Microcline was never found. The nodules consist

of optically subparallel cordierite crystals, elongated parallel to s_e, with lamellar twinning and some plagioclase. Alteration is rare. Enclosed within cordierite and plagioclase lie quartz bands, isoclinally microfolded with their axial planes parallel to the schistosity (fig. 49). Muscovite is very common within cordierite. The unbent flakes lie parallel to the microfolds. This microfolded s_i is supposedly similar to the microfolded fabric observed enclosed in plagioclase of normal paragneiss. Plagioclase in or near cordierite nodules does not contain muscovite. Coarse-grained biotite is completely absent; on the contrary, biotite is very small and rounded as if resorbed. Ore is much commoner within than outside cordierite (determined in polished section: ilmenite + hematite lamellae, pyrrhotite, chalcopyrite, pyrite).
Since cordierite has grown to sizes many times larger than other minerals (except plagioclase) it is also metablastic. Direct age relations between the two minerals were seen only once and in that case the relation might be uncertain because of the absence of a section in the third dimension: fig. 43 suggests that cordierite, surrounding plagioclase fragments with the same twins as an adjacent plagioclase, is younger than plagioclase. Cordierite crystallized under tectonic stress as appears from the subparallel orientation of grains and is therefore older than the large non-bent, unoriented biotite flakes. Small-scale E-W folds of banded paragneiss were observed in some outcrops (fig. 50). Microfolded quartz bands are nowhere so well visible as in the cordierite nodules. Probably they were obliterated elsewhere by the "Sammelkristallisation" of quartz and biotite.
As far as can be deduced from microscopical observations, cordierite formed together with muscovite and ore at the expense of biotite.

Lonsa-type paragneiss

The arguments that led the author to the assumption that the finely banded, fine-grained gneisses of the Lonsa-type are relics of thermometamorphic aureoles around the pre-hercynian granites now present as NE orthogneisses, will be given here.
Traces of hercynian deformation are rare in the Lonsa-type gneisses. Microfolds or small-scale folds were not found. Schistosity (parallel or oblique to the banding) is inconspicuous or absent. The rocks were probably more rigid during the hercynian orogeny than the metasediments further away from the orthogneiss contacts.
It is often difficult to distinguish hercynian metamorphic minerals from older ones. Macroscopically, plagioclase metablasts are small when visible at all; in thin section they nearly always appear. They are larger in mica-rich bands than in laminae rich in quartz; enclosed elongated quartz crystals are more common in the latter than in the former. Coarse-grained quartz and biotite outside metablasts are absent in the most characteristic rocks of this type. From this the conclusion may be drawn that, in addition to deformation, also metablastic recrystallization and „Sammelkristallisation" had less effect upon the Lonsa-type gneisses. Small biotites lie parallel to the banding and to the long axes of elongated quartz.
Several specimens contain fine-grained aggregates of cordierite. In contrast with Pereiras-type cordierite the mineral is often altered here. Since it has been found enclosed within metablastic plagioclase it is definitely older than plagioclase; metablastic plagioclase is early hercynian, so the cordierite is probably pre-hercynian. Xenoblastic andalusite and some fibrolite needles were noted in a few cordierite aggregates. Their relative ages could not be decided upon. The fine-grained old cordierite in finely banded, rigid and weakly metablastic rocks adjacent to orthogneisses demonstrate their thermometamorphic past.
From the presence of trains of elongated quartz and of elongated quartz crystals

in small plagioclase metablasts, both parallel with the banding, it follows that their origin is pre-hercynian.

Other rocks found in the same area have less clearly relictic hornfels textures. They are occasionally rich in probably late-grown sillimanite and andalusite and coarser-grained. No evidence of instability of sillimanite, andalusite and cordierite could be detected in such rocks, not even when they are in contact with each other.

Some specimens contain parts with (fine-grained) cordierite, sillimanite, (andalusite, corundum), quartz, biotite and plagioclase surrounded by coarser quartz-plagioclase-biotite mosaics. Such rocks have about the same mineralogical compositions as the cordierite-quartzdiorites with alumina-rich xenoliths outcropping more to the NW, while only the textures of the mosaics differ, the alumina-rich parts being very similar to the xenoliths. Although in outcrops migmatic phenomena are absent altogether and the quartzdiorite is clearly intrusive, the striking similarity suggests that not far below the present erosion level, anatexis has mobilized such paragneiss and formed the restite-rich melt that intruded as a "stockwork".

The descriptions of the four sub-types of Lonsa-gneiss in chapter VII demonstrates the immense variety in mineralogical compositions and textures. In fact each rock would have to be described separately; even the moderate generalization made by the distinction of four sub-types is inaccurate and confusing. All this becomes understandable when one realizes that in these rocks the effects of so contrasting phenomena as thermometamorphism, regional metamorphism and recrystallization leading to anatectic mobilization at deeper levels are superimposed upon each other.

Pre-hercynian or pre-thermometamorphic aspects

Proceeding now to the pre-hercynian resp. pre-thermometamorphic features of all paragneisses together, the following minerals or structures remain to be explained: the turbid, resorbed garnets, enclosed within plagioclase and cordierite metablasts and also within quartz, tourmaline and apatite that is in its turn surrounded by andalusite, generally without alternation products; the small parallel biotite flakes in plagioclase metablasts and in Lonsa-type gneisses; the "trains" of elongated quartz grains and elongated quartz crystals enclosed within plagioclase metablasts and that occur also, parallel to the lamination, in the relictic hornfelses.

They present the scanty but sufficiently conclusive remnants of an older metamorphism, during which the s_i originated. According to Oen Ing Soen (oral communication) resorbed turbid garnets and other vestiges of a pre-hercynian metamorphism were also found in the neighbourhood of Oliveira de Azemeis, N Portugal.

It is improbable that old metamorphism and local thermometamorphism were contemporaneous since their mineral assemblages (as far as known) are characteristic of quite distinct crustal levels. This is also evidenced by the observation that the thermometamorphic relics carry resorbed garnet but less often so than the normal paragneisses. The conclusion seems warranted that the ancient regional metamorphism is older than the intrusion of the granites now present as orthogneisses. In their aureoles garnet became instable and was mostly broken down.

Whether the ancient metamorphism was accompanied by the folding of s_i which is occasionally visible enclosed within metablastic plagioclases remains uncertain; it could as well be early hercynian:

The deformation preceding the hercynian metamorphism was strong as evidenced by the pronounced foliations of the granite-gneisses. The obvious relict structures of ortho-amphibolites (figs. 27, 28), on the other hand, demonstrate that rocks could escape being deformed, provided they are sufficently different in competence. The style of hercynian folding of the paragneisses, described earlier in this section, made clear that within the paragneiss complex differences in competence can also be pronounced. It is therefore possible that some competent paragneisses were hardly deformed by the hercynian deformations, and consequently that folded s_i in such rocks is pre-hercynian. Other rocks (e.g., the quartz- and biotite-rich cordierite gneisses of the Pereiras-type) do not make the impression of having been competent before the hercynian deformation. Folding of s_i could therefore be early hercynian in them.

The question arises whether cordierite-bearing thermometamorphic assemblages could originate at all in regional metamorphic rocks. The fact that the metamorphic biotite, quartz and garnet were fine-grained suggests that the whole rocks were fine-grained, which probably facilitated subsequent recrystallization. A similar case was described by Long & Lambert (1963; appendix A). The hornfels contact around the Carn Chuinneag orthogneiss complex (Scotland) contains resorbed garnets which do not fit well into the paragenesis, when it is assumed that their growth was due to thermal metamorphism. This and other arguments given by the authors mentioned, pleaded in favour of an earlier regional metamorphism surpassing the garnet isograde. In the Carn Chuinneag contact aureole, sedimentary structures are well preserved and later deformation is inconspicuous, just as in Lonsa-type gneisses.

The age of the pre-hercynian regional metamorphism is uncertain. As stated in the relevant sections, intrusion of the Rb-Sr dated pre-hercynian granites took place close to the Cambro-Ordovician junction. The ancient regional metamorphism should therefore be older than Upper Cambrian. Capdevila (1966) demonstrated that in the NW of Spain assyntian movements were inconspicuous or absent. The metamorphism has therefore to be of Precambrian age. More data and considerations on this Precambrian metamorphism are given in the proceedings of the "Primera Reunión sobre geologia de Galicia y norte de Portugal" (1966).

The original sediments in the area studied were banded rocks of a variable composition. The bands observed now have thicknesses of a few cm up to a few dm or more; in Lonsa-type gneisses the banding is narrower. The finely banded gneisses may not be seen elsewhere because their structure was obscured by metablastic recrystallization or because they were absent in the rocks that are now normal paragneisses. Since fine-grained, but microcline-bearing arkosic gneiss is present between Zamanes and Filgueiras, the first alternative does not seem to be the most logical one.

The quartz crystals in plagioclase metablasts probably represent the quartz grains of the original sediments. Because nearly all paragneisses of the area are rich in plagioclase and mica, the original sediment probably was a greywacke. The higher content of sodium than of potassium (see chemical analysis, table 18) also points to the fact that the original rocks were greywackes and not arkoses.

Pelitic schists are rare in the author's area. More to the west a micaschist band is well exposed, e.g. at Monte Ferro and Cabo de Hume.

Impure calcareous sediments provided the material for the para-amphibolites and related rocks. Hornblende-bytownite schists were described from Portugal by Schermerhorn (1956) and Sluijk (1963). They have compositions roughly similar to the author's para-amphibolites but contain bytownite without metablastic habit

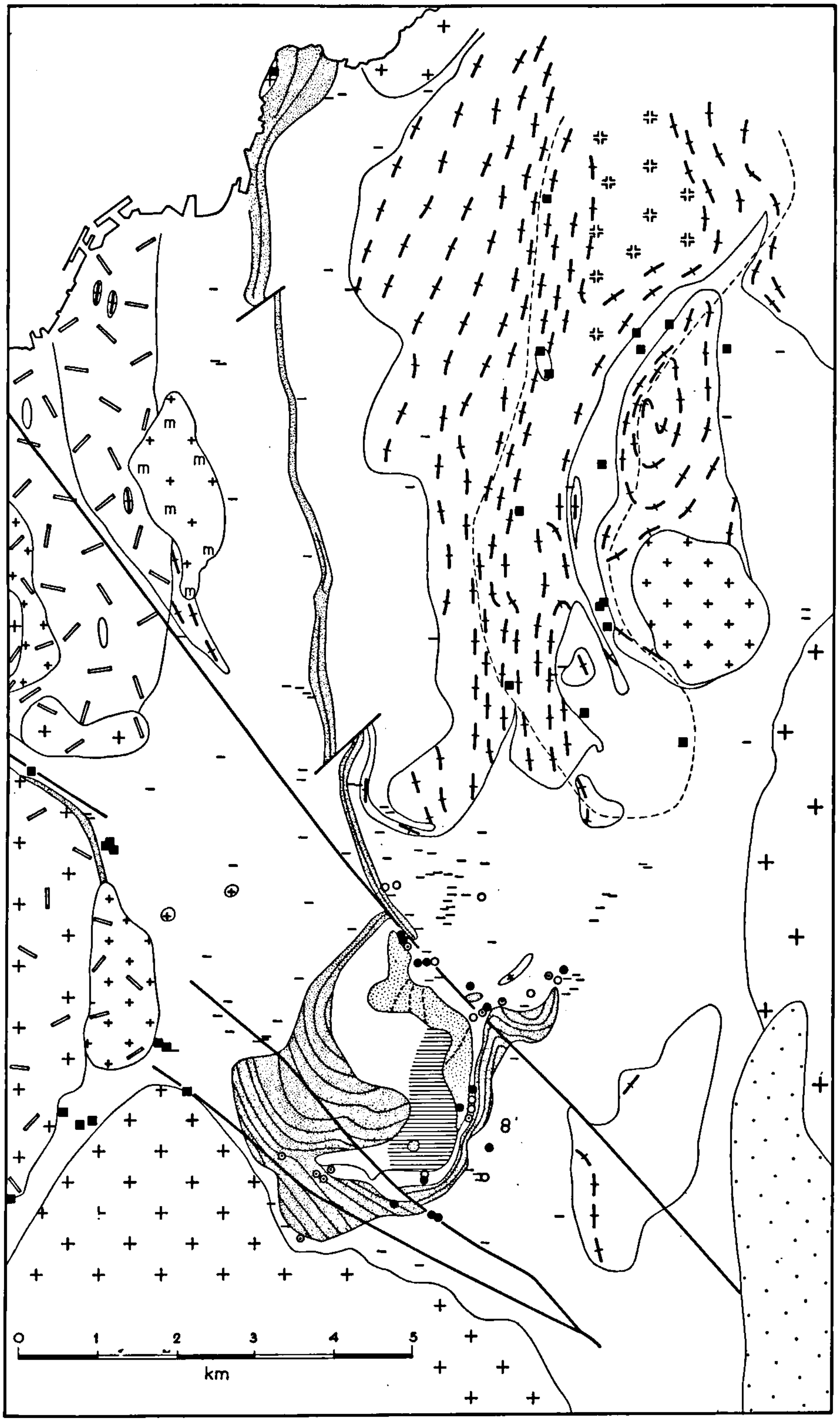


Fig. 53 Microcline in the southern half of the investigated area. Open circles: fine-grained paragneiss; solid circles: microcline-bearing fine-grained paragneiss; dotted circles: microcline not in fine-grained paragneiss. Horizontal hatching: area of distribution of "amphibole-biotite gneisses with relatively coarse quartz and albite in a fine mass of feldspar and quartz". Muscovite lepidoblasts (solid squares), area of distribution of granites associated with cordierite-quartzdiorite (dashed line) and locations of samples without microcline or lepidoblastic muscovite (horizontal dashes).

and no cummingtonite. The titanium content of these metasediments also puzzled Sluijk (1963; p. 59; this paper, table 16).

Metablastic paragneisses as found in the investigated region were not described from northern Portugal. Teixeira (1955) mentions the occurrence of plagioclase-bearing paragneiss between Valença and Braga, due south of the Galiñeiro area. The specimens collected by the author near Valença have a granoblastic texture; no petrographical descriptions are known from paragneisses more to the south.
Between this zone of plagioclase-bearing paragneisses and the atlantic coast a belt of schists, intruded by two-mica granites, is present in both countries (fig. 1). Intraformational conglomerates are numerous in this series in Portugal, while in Galicia only one occurrence has been found near El Rosal, just north of the frontier (Dr. I. Parga-Pondal, oral communication).

Between schist and paragneiss a NNW-SSE trending tectonic lineament is present (Carta geologica de Portugal, 1961; folha 1-C, Caminha), the continuation of which into S Galicia has not yet been mapped in detail (fig. 1). It is therefore not known whether this zone separates rocks of different compositions, grades of metamorphism or ages.
To the present author the latter possibility seems improbable because further north in Galicia arguments in favour of widely different ages of schists and paragneisses (e.g. ancient disconformities, metamorphosed basal conglomerates) were not found. He therefore considers the Precambrian metasedimentary rocks of W Galicia as the immediate continuation of the paragneisses and schists in NW Portugal, where they are called "Complexo xisto-grauváquico ante-Ordoviciano" (Teixeira, 1955). These rocks are thought to be of Infracambrian age by Teixeira (1955), while Schermerhorn (1955) assigns an Infracambro-cambrian age to them. Parga-Pondal, Matte & Capdevila (1964) seem to incline to the same opinion because of the Cambrian lithology of the upper part of the complex. It is clear that at least one of these correlations is incorrect. The author does not know the whole area involved from personal study and is therefore unable to indicate which correlation is correct.

Contact influence of hercynian granites

Thermometamorphic influence of two-mica granite is rarely evident in paragneiss. Perhaps it stimulated local recrystallization of quartz and plagioclase into granoblastic mosaics.
Muscovite lepidoblasts with ragged terminations (fig. 44) were found exclusively in the neighbourhood of muscovite-bearing granitic rocks (fig. 53). They occasionally enclose sillimanite, a mineral which was observed once in quartz and biotite. The muscovite strikingly resembles the lepidoblastic crystals present within the granite. The late- or post-magmatic processes that generated these muscovites apparently exerted their influence also in adjacent gneisses. The same was noted by a.o. Schermerhorn (1956) and Oen Ing Soen (1958) around N Portuguese two-mica granites.
Seki & Kennedy (1965) established that solutions rich in potassium and silica can originate when water in a cooling magma reacts with potassium feldspar to form muscovite. If such solutions migrate into the surrounding rocks, they can generate muscovite if the P_{H_2O}-T conditions reigning there are within the stability field of that mineral (cf. fig. 51).
Tourmaline enrichment in paragneiss is common especially near coarse-grained equigranular two-mica granite and associated pegmatites.

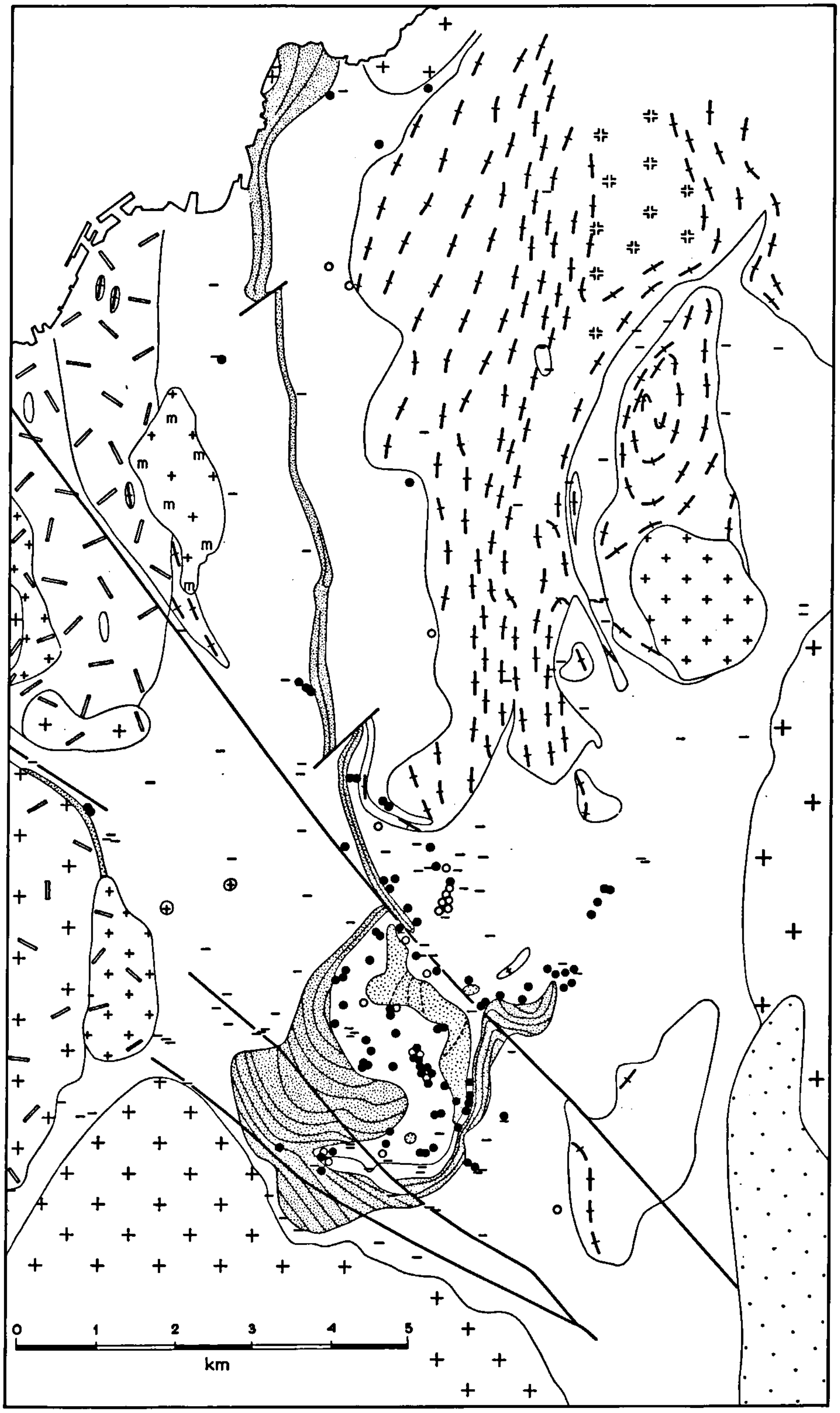


Fig. 54 Albite blastesis in paragneiss and amphibole-biotite rock and gneiss with sedimentary origin. Solid circles: albite-rich rocks; open circles: rocks with little albite; horizontal dashes: albite-free rocks.

Few paragneiss specimens were collected from the vicinity of coarse-grained biotite granite and megacrystal granite. Their thermometamorphic influences could therefore not be investigated. From megacrystal granite it is known that it caused orthogneiss to recrystallize.

Metasomatism from riebeckite gneiss

Continuous sections through contacts from normal paragneiss to normal riebeckite gneiss are nowhere exposed. One therefore has to collect evidence from many scattered outcrops or specimens, all representing only part of the whole process. Some conclusions may therefore turn out to be of only local value, while being used here as if generally applicable.

As is evident from fig. 54 the distribution of albite porphyroblasts that replaced metablastic oligoclase or grew without replacing any special mineral is clearly controlled by the presence of riebeckite gneiss. The porphyroblasts have mostly simple (010) twins and enclose less quartz and dark minerals than metablastic plagioclase (especially obvious when only part of the oligoclase has been replaced). Tiny idiomorphic prisms of zircon and rutile were often found within albite. They are completely absent outside the albites and therefore clearly related to them. Further away from riebeckite gneiss albite is present in a few gneisses, probably as a retrograde metamorphic mineral. In such albite no zircon or rutile needles were seen! Paragneisses found in the continuation of the eastern riebeckite gneiss band, turned out to be very rich in zircon/rutile-bearing albite. This might possibly indicate that riebeckite gneiss is present unexposed northeast of its visible extremity. Albite porphyroblasts are never deformed so they crystallized after the hercynian penetrative movements, about contemporaneously with albite in riebeckite gneiss. The metasomatic introduction of sodium into adjacent paragneisses from riebeckite gneiss has probably been caused by the complete separation of microcline and albite phases of the original perthites by the hercynian deformation.

The distribution of microcline in paragneiss (fig. 53) demonstrates that the presence of microcline, when not a late alteration product (cf. Chayes, 1955) or original component, is also somewhat dependent upon riebeckite gneiss. In one sample collected near a contact microcline replaced metablastic oligoclase, while albite with enclosed amphibole needles replaced microcline. So in this case microcline is late-hercynian. Elsewhere such relations could not be observed.

Metasomatism from per-alkaline granite

Thermometamorphic influence from per-alkaline granite upon paragneiss could not be observed with certainty. (Per-alkaline granites are poor in H_2O; see discussion in section riebeckite gneiss about the original granite). Some paragneisses are considerably enriched in zircon (irregular crystals larger than their normal—rounded—ones). Since they even occur in some rocks not very distant from riebeckite gneiss but without albite porphyroblasts the introduction of zirconium was independent from that of sodium and might have taken place during the intrusion of the granite.

Important (sodium-) metasomatism from per-alkaline granite into paragneiss has to be invoked to explain the origin of some amphibole-biotite gneisses, to be discussed in the next section.

THE AMPHIBOLE-BIOTITE ROCKS AND ASSOCIATED GNEISSES

As stated in the introduction (ch. I), the complex of amphibole-biotite rocks and associated gneisses has been divided into a western, metasedimentary part and an eastern with an igneous origin. Normally, the differences cannot be seen in the field; distinction is based principally upon microscopic evidence: the presence of large idiomorphic zircons in the granite-gneiss and of smaller xenomorphic or rounded zircons in the other part. The rocks with sedimentary origin will be described first since their history is directly connected with the processes mentioned in the last paragraph of the preceding section.

Rocks of sedimentary origin

Several types of amphibole-biotite gneiss from the western part of the complex were distinguished in chapter IV and on plate 2. The differences are mainly in texture and quantities of the minerals quartz, plagioclase (metablastic oligoclase and albite) and microcline.

Discordant microcline-rich pegmatites were occasionally noted; their origin was already explained in the section concerning riebeckite gneiss. Gneisses as described here are not known to occur anywhere else in Galicia or Portugal.

Oligoclase metablasts in the "amphibole-biotite rocks with plagioclase enclosing quartz droplets" contain small crystals of dark green amphibole, greenish brown biotite and titanite, thus demonstrating that these minerals already existed before the growth of the metablasts. Oligoclase is rare or fine-grained in the other types and the existence of the same relations in them could therefore not be verified. Reaction fabrics of quartz and the feldspars are very frequent. The dark constituents crystallized in comparatively large undeformed crystals indicating a rough foliation mainly outside the oligoclase metablasts or quartz-feldspar masses ("Sammelkristallisation" of German authors). Some rocks with oligoclase metablasts are free of porphyroblastic albite, whereas others are richer in the same mineral and those in the immediate vicinity of the per-alkaline gneiss consist of albite nearly to the exclusion of other light minerals.

Summarizing, it may be said that crystallization of post-tectonic albite like that in paragneiss is superimposed upon earlier processes; microcline is present in rocks almost free of albite, so this mineral can hardly have grown together with this late generation of albite. The pre-hercynian rocks were such that metablastesis could generate oligoclases with enclosed crystals and droplets of quartz in some of them in the same way as in paragneiss; they must have been carrying already dark green (ferrohastingsitic, i.e. sodium-bearing) amphibole, greenish brown biotite and titanite.

The localities of the "amphibole-biotite gneisses with relatively coarse quartz and albite in a fine mass of feldspar and quartz" appeared to lie in the same N-S trending zone from Filgueiras to north of Zamanes where fine-grained, microcline-bearing paragneisses are exposed outside the amphibole-biotite gneiss complex (fig. 53).

This coincidence, the facts summarized above and the position of the rocks under discussion adjoining the thickest part of the riebeckite gneiss complex, wich probably extends underneath them, led the author to the hypothesis that they are the same as those rocks still present as paragneiss in the neighbourhood, but modified into rocks with amphibole and microcline by metasomatic introduction of the necessary elements from the per-alkaline granite.

The metasediments into which that granite intruded were — as far as could be established — fine-grained biotite-plagioclase gneisses and fine-grained microcline-bearing biotite-plagioclase gneisses.

Since sodic green amphibole and greenish brown biotite do not contain much titanium, this element could form titanite. Paragneisses carry biotite, the rocks under discussion also contain amphibole; not all potassium could therefore be incorporated in the dark minerals and the rest crystallized as microcline. In addition, some introduction of potassium, known to have taken place in xenoliths within riebeckite gneiss, is not impossible here either.

The absence of pre-hercynian metasomatism along the inner boundary of the eastern riebeckite gneiss band and along the W band between La Guia and Zamanes is probably due to the much smaller thicknesses of those bands. Late-hercynian albite

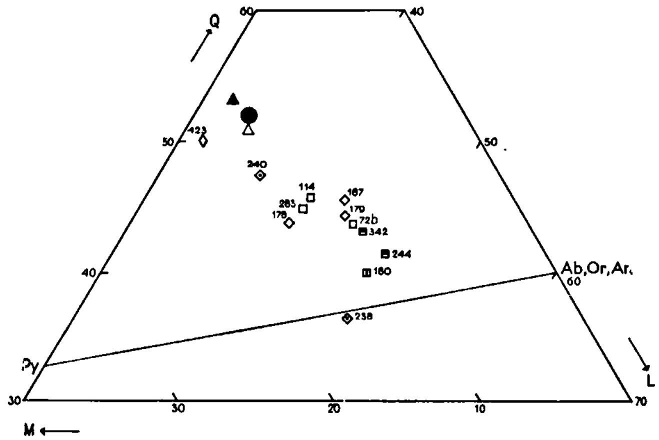


Fig. 55 Partial QLM-diagram of amphibole-biotite rocks and gneisses with sedimentary origin (legend of symbols on plate 2). Q, L and M of analyses on table 18 are plotted for comparison: lozenge: paragneiss (423); open triangle: average intermediate schistose paragneiss, Black Forest, Germany; solid triangle: average paragneiss, Black Forest, Germany; solid circle: average greywacke.

and sometimes microcline, on the contrary, were seen there. Sodium apparently became more mobile during the hercynian recrystallization of the riebeckite gneiss than during the crystallization of its original per-alkaline magma.

Chemical analyses were made to see whether they would prove the action of metasomatic replacement. Their exact interpretation is impossible, because the original compositions of the rocks (even when now classified in the same type) need not have been exactly the same. Moreover, the pre-hercynian processes might have influenced some rocks much more strongly than others, while late-hercynian processes did the same and possibly on other rocks. Nevertheless, the QLM diagram (fig. 55) using QLM values from plate 2 demonstrates that the projections of the analyzed specimens did indeed shift towards the feldspar locus on the QL join when compared with analyses of sedimentary rocks with greywacke composition. Analyses of the albite-rich types plot nearest to the feldspar point.

Rock macroscopically resembling amphibolite was found only once. In thin section, however, the "fine-grained, amphibole-rich melanocratic rock" of specimen 281 (see ch. IV) is very rich in microcline. When this composition should have resulted from metasomatic changes of a normal amphibolite, these processes must have influenced the dark-coloured rock more strongly than the surrounding gneiss which is much poorer in microcline. In the author's opinion this is rather improbable. Since the dark-coloured rock resembles those found in the eastern part of the complex, its probable origin will be further discussed below.

The frequency of amphibolites in paragneiss is such that the fact that they were not found in amphibole-biotite gneiss does not necessarily contradict the theory of the origin of this gneiss, as exposed above.

Rocks of igneous origin

The eastern complex of amphibole-biotite rocks and gneisses is much more heterogeneous than the western part. Not less than ten groups, types and varieties had to be described in chapter IV. Foliation is inconspicuous, except in "leucocratic planar gneiss". Small-scale or microfolds were not observed. The field relations of many of them show that assimilation and hybridization must have assisted in their genesis. Their properties will be very briefly summarized below.

"*Dark-coloured biotite-amphibole rocks with basic plagioclase*" are composed of green hornblende ($2V_\alpha$: 70°–80°) and limpid oligoclase to andesine (enclosing clinopyroxene droplets, fig. 19) around altered masses of more basic plagioclase (up to bytownite). The plagioclase masses, which in some samples clearly have the outlines of large ancient plagioclases, are fine-grained. Twins in the large ancient plagioclases have been conserved during the recrystallization and are now visible as distinct optical orientations of parallel straight rows of small plagioclase grains. These features are prominent in basic plagioclase, inconspicuous in the more acid varieties. They are therefore visible only in rocks with relatively fresh basic plagioclase. Microcline is intergrown only with acid plagioclase; the latter is inversely zonal. Clinopyroxene was also noted in hornblende, as implication intergrowths with the participation of plagioclase (fig. 20). Schiller inclusions were found in a few hornblendes. Minute titanite droplets are numerous in some parts of hornblende, while absent elsewhere in the same crystal. Titanite replaces ilmenite.

These rocks probably represent pre-hercynian gabbros containing pyroxene somewhat richer in titanium than the actual hornblende, and with occasional Schiller inclusions. Only once a foliated rock was found; the gabbros apparently reacted upon the metamorphism in the same way as did the amphibolites: principally by recrystallization of plagioclase into fine-grained aggregates and by the formation of hornblende instead of pyroxene. Diopsidic pyroxene droplets formed locally, using lime from the basic plagioclase. There are also rocks without clinopyroxene, however, and they have exactly the same acid plagioclase intergrown with microcline as the clinopyroxene-bearing rocks, so the formation of clinopyroxene cannot account alone for the decalcification of the plagioclase.

"*Dark-coloured biotite-amphibole rocks with acid plagioclase*" are non-foliated, finer-grained rocks than the former. Their content of dark minerals (green amphibole, $2V_\alpha$: 50°–70°, cores occasionally lighter-coloured and with larger 2V, and biotite) is higher. Plagioclase is much more acid: 10–30 % An, not zonal but with a patchy distribution of different anorthite contents; enclosed clinopyroxene is very rare. Blastic albite was noted (fig. 22). Zircon and allanite are more common, zircon encloses apatite (fig. 23).

The "*quartz- and albite-poor type of meso- to leucocratic biotite-amphibole rock*" was only found in the immediate vicinity of the two above-mentioned rocks. Quartz crystals were not noted, albite blastesis is inconspicuous. Two specimens consist of microcline only, others of microcline and oligoclase. Zircons are idiomorphic and in one sample larger than any of the other minerals.

"*Leucocratic planar gneisses*", similar to riebeckite gneiss but with biotite, dark green amphibole or both, and with some oligoclase relics in a few thin sections, do not show hybrid relations with other rocks. In the NE orthogneiss complex some rocks have about the same mineralogical compositions as the gneisses mentioned here.

"*Biotite-amphibole rocks with albite embedded in a relatively fine-grained mass of microcline, plagio-*

clase and quartz" were all collected NW of Herbille. They resemble leucocratic planar gneiss but are finer-grained, contain more dark constituents, more plagioclase with a slightly more basic composition than the abundant albite and less coarse microcline. Idiomorphic zircons reach diameters of .4 mm.

"*Microcline-poor quartz-albite rocks*" probably carry albite as a primary constituent since it has no porphyroblastic habit, while more basic plagioclase is absent. They were found mainly within leucocratic planar gneiss, except for a body that has the appearance of a dyke in the field. Dark minerals are: (more or less) ferrohastingsitic green amphibole, biotite and (in the dyke-like rock) relics of green clinopyroxene. One specimen contains round, inclusion-free albites around fluorite. The same relation was found in some riebeckite gneiss samples. The accessories include in addition to fluorite: pyrochlore, monazite, xenotime, zircon and allanite, an assemblage that strongly suggests an igneous origin.

The name "*fine-grained variety*" of microcline-poor quartz-albite rock is self-explanatory.

The "*fine-grained, oligoclase-bearing variety*" resembles the fine-grained variety of this type but contains some oligoclase relics like some leucocratic planar gneisses.

"*Albite-rich, quartz- and microcline-poor types*" are actually accumulations of oval albites with some interstitial quartz, microcline, green amphibole and biotite.

"*Fine-grained amphibole-rich melanocratic rocks*" can be roughly divided into two compositional varieties: one mainly composed of green amphibole and microcline, with minor amounts of biotite and plagioclase and the other with mainly plagioclase (oligoclase and albite) and green amphibole, with minor amounts of biotite and microcline. The former variety was mentioned in the section concerning amphibole-biotite gneisses of sedimentary origin, where it was argued that the composition of the wall rock makes large-scale replacement of possible original plagioclase by microcline unlikely. Albite was introduced by blastic growth in the second variety in the same way as in many other rocks.

Recrystallization has played a more important role in most rocks than deformation as follows from the fact that they are only weakly foliated. The deformative stresses seem to have acted more strongly outside than within the riebeckite gneiss arc. Blastic albite, common in several types, has the same properties as in rocks dealt with before. Its origin should therefore be the same: introduction of the necessary components from neighbouring per-alkaline gneiss in which albite has completely separated from microcline.

Because of its extreme textural similarity with riebeckite gneiss it is not impossible that the leucocratic planar gneiss also contained originally one perthitic feldspar (i.e.: was a hypersolvusgranite); it could therefore have been the source of sodium for part of the adjacent rocks.

Discordant pegmatites were found at several places; their genesis was discussed together with those in amphibole-biotite gneiss of sedimentary origin and in riebeckite gneiss in the section regarding the latter rocks.

A completely distinct vein is composed mainly of albite. It probably originated by lateral secretion since it has irregular outlines and amphibole concentrations along its walls.

The pre-hercynian history remains speculative; the following facts facilitate the establishment of age relations within the complex and between rocks of the complex and others outside.

Amphibolites with relict igneous structures, as present in NE orthogneiss, were not observed, but not in the immediate vicinity of the complex either. Metagabbros with relict igneous textures ("dark-coloured biotite-amphibole rocks with basic plagioclase"), however, make up part of the complex and were observed to be surrounded by more leucocratic rocks of the "quartz- and albite-poor type" as if they were relics in a process of assimilation. The same type of leucocratic rock was observed to be in contact with "dark-coloured biotite-amphibole rock with acid

plagioclase". Fragments of "dark-coloured biotite-amphibole rock" were observed macroscopically in "biotite-amphibole rocks with albite embedded in a relatively fine-grained mass of microline, plagioclase and quartz". The latter also enclose fragments of "fine-grained amphibole-rich melanocratic rocks" with diffuse contacts (865A and 865B, fig. 25). The amphibole-rich rocks in these cases appeared to be relatively rich in plagioclase. On the other hand plagioclase-poor "fine-grained amphibole-rich melanocratic rock" resembling a narrow dyke (764), has a sharp contact with "biotite-amphibole rock with albite embedded in a relatively fine-grained mass of microcline, plagioclase and quartz". In the last paragraph of the part concerning rocks of sedimentary origin mention has been made of a sharp contact of "fine-grained amphibole-rich melanocratic rock" (281, also occurring as a dyke-like body: ch. IV). As argued above, that sample (like 764 plagioclase-poor!) cannot have originated through metasomatic changes from a normal amphibolite. Since the transitional zones at the contacts of both samples are similar, it is thought that they were the same kind of amphibole- and microcline-rich, fine-grained rocks (lamprophyres?) that recrystallized and formed their transitional zones during the hercynian metamorphism. Since fragments of "fine-grained, amphibole-rich melanocratic rock" (768) very much resembling 764 and 281 were found in "albite-rich, quartz- and microcline-poor type of meso- to leucocratic biotite-amphibole rock" the latter should be younger than the former and therefore also younger than "biotite-amphibole rock with albite embedded in a relatively fine-grained mass of microcline, plagioclase and quartz" (relation of 764). If all this should be true, there is also a difference in age between the plagioclase-poor and relatively plagioclase-rich fine-grained melanocratic rocks, the latter being somewhat older, as outlined above.
Direct age relations between other groups, types and varieties than those listed above could not be established. Since riebeckite gneiss and NE orthogneiss have no contacts with amphibole-biotite rocks, their age relations with them remain equally inexact.

In non-metamorphic occurrences of riebeckite and biotite hypersolvus granites the relations show biotite granite to be either older (Jacobson, MacLeod & Black, 1958), contemporaneous (Raulais, 1960) or younger (Rocci, 1960b). Analogies with non-metamorphic terrains are therefore of no help in discussing the age relations of "leucocratic planar gneiss" and riebeckite gneiss. Like the latter, the former are homogeneous in texture and enclose only a few xenoliths, which are enriched in microcline.

History of the complex

The facts given above lead to the following picture of the origin of the complex:
Gabbroic rocks were intruded by an alkaline or per-alkaline magma with large zircons. Part of the gabbro was assimilated by the magma which thereby became hybrid and is now present (modified by hercynian metamorphism and metasomatism) as "biotite-amphibole rock with albite embedded in a relatively fine-grained mass of microcline, plagioclase and quartz". In the vicinity of gabbroic relics this rock is still poorer in quartz and distinguished as "quartz- and albite-poor type of meso- to leucocratic biotite-amphibole rock". There also seems to have been a process which depleted the original gabbro in plagioclase, that at the same time (or later?) became more acid in composition, yielding "dark-coloured biotite-amphibole rocks with acid plagioclase".
In addition to coarse-grained gabbro, fine-grained rocks with a relatively high

content of dark constituents were also intruded. These are now present as fragments of "fine-grained amphibole-rich melanocratic rock", relatively rich in plagioclase.
Melts of possibly lamprophyric composition, rich in dark minerals and potassium feldspar, intruded locally into the "biotite-amphibole rock with albite embedded in a relatively fine-grained mass of microcline, plagioclase and quartz" and adjacent rocks of sedimentary origin.
The dykes that crystallized from the lamprophyric melts were in their turn fragmented by "albite-rich, quartz- and microcline-poor type of meso- to leucocratic biotite-amphibole rock".
Leucocratic, biotite-, perthite- and sometimes amphibole-bearing granite intruded just north of the area where the above-mentioned rocks are cropping out. It is

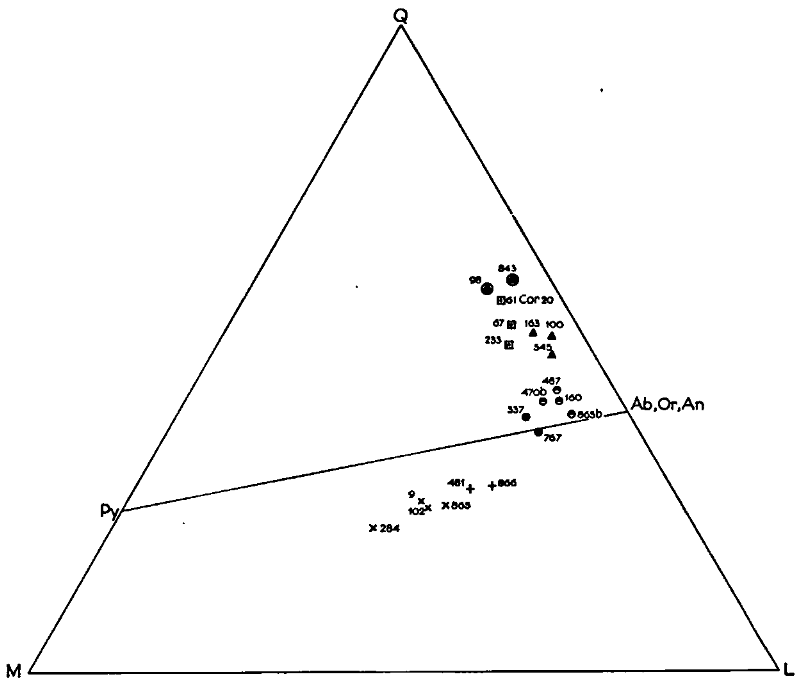


Fig. 56 QLM-values of amphibole-biotite rocks and gneisses with igneous origin (legend of symbols on plate 2) and riebeckite gneiss (squares, data from table 9).

unlikely that it crystallized from the same magma as that which caused the assimilation. No samples were collected with compositions clearly transitional between "leucocratic planar gneiss' and "biotite-amphibole rock with albite embedded in a relatively fine-grained mass of microcline, plagioclase and quartz", while these would be expected if part of the magma were contaminated by assimilation of wall rock.
The "microcline-poor quartz-albite rock" and its fine-grained variety seem to have been intrusive into "leucocratic planar gneiss"; their relative ages depend upon that of the planar gneiss and consequently vary with the interpretation of that age.
The light-mineral content of the "microcline-poor quartz-albite rocks" resembles that of the radioactive gneisses connected with the riebeckite gneiss complex and

considered as a late differentiation product of that complex. The fine-grained oligoclase-bearing variety is probably a hybrid type.

The hercynian metamorphism, causing recrystallization, metamorphic differentiation, albitization etc. in some or all types, has considerably changed their mineralogical and chemical compositions. Incertainty as to the extent to which these processes are responsible for the actual appearance and composition of the amphibole-biotite rocks renders a quantitative statement on their original compositions, using chemical analyses, impossible.

In the QLM diagram (fig. 56, data from plate 2) the hybridization of an original magma by an admixture of gabbroic material is well visible as a considerable shift in composition toward the latter, especially when allowance is made for the later introduction of albite; subtraction of part of the normative albite and recalculation of QLM makes the plots of the contaminated rocks shift to the left. The original magma must have had a composition near that of "leucocratic planar gneiss" or riebeckite gneiss (QLM values calculated from analyses in table 9). The "dark-coloured biotite-amphibole rocks with acid plagioclase" are clearly impoverished in feldspar, while it is not impossible that the samples 337 and 767 represent material extracted from them during the hybridization.

Examples of assimilation of basic rock by granite are not rare in the literature. Only a few, that offer special aspects, will be quoted here.

Na-bearing amphibole, (partly more acid) plagioclase, biotite and titanite are described by Buddington (1939) to have formed in pyroxene diorite under influence of hot solutions emanating from a granitic magma. Nockolds (1933) pointed out the fact that the concentrations of apatite and titanite are higher in the assimilation products than in either intrusive or intruded rocks.

It is remarkable that hybridization took also place in the orthogneiss complex of Carn Chuinneag, Scotland, mentioned several times before in this chapter, because it also presents examples of riebeckite gneiss, unmixed perthites and of hornfelses in regionally metamorphic rocks, analogous to phenomena in the Galiñeiro area. Since around Carn Chuinneag no later albitization took place (the basic rocks were intruded and assimilated by normal granite; Harker, 1962), the history is less complex than in the area under discussion but more so than in complexes that were not metamorphosed after the hybridization.

GRADE AND AGE OF HERCYNIAN METAMORPHISM

The *grade* of the main phase of hercynian metamorphism, as evidenced by the occurrence of andalusite, cordierite and cummingtonite on a regional scale, was that of the low-pressure side of the amphibolite facies; in the nomenclature of den Tex (1965) it belongs to the high-temperature lineage of orogenic plutonism.

The association is characteristic of the andalusite-sillimanite type of regional metamorphism as defined by Miyashiro (1961). In his study on the central Abukuma Plateau, Miyashiro (1958) divided this type into three zones (A, B, C) of increasing metamorphic grade. Potassium feldspar and cordierite are present only in certain rocks of zone B, but it seems that in this zone the two minerals cannot coexist; andalusite is common, cummingtonite rare. The colour of γ of hornblende is blue-green. In zone C, on the other hand, potassium feldspar is formed on a large scale as a product of the reactions:

$$\text{biotite} + \text{muscovite} + \text{quartz} \rightleftarrows \text{cordierite} + \text{K-feldspar}$$
$$\text{muscovite} + \text{quartz} \rightleftarrows \text{sillimanite} + \text{K-feldspar}$$

The transition of andalusite into sillimanite occurs in the lower part of zone C. Cummingtonite is common and the colour of γ of hornblende is green.

Since in the Galiñeiro area potassium feldspar was found only in a limited number of rocks, andalusite is more wide-spread than sillimanite, whereas cummingtonite is not rare in certain types, the assemblage is characteristic partly of that of zone B, partly of zone C. It is therefore tentatively placed at the transition of zones B and C. Perhaps a deficiency of potassium in cordierite-bearing rocks assisted in the formation of andalusite and muscovite instead of K-feldspar (Turner & Verhoogen, 1951, p. 448; Hemley, 1957, p. 268).

Within the high-temperature lineage of den Tex (1965; fig. 6) the rocks would belong to the andalusite-(staurolite)-cordierite subfacies (after Zwart, 1963) of the amphibolite facies (T $\pm$ 500°–600° C; P $\pm$ 2.5–5 kb). In the nomenclature of Winkler (1965; p. 101) the association forms part of the andalusite-cordierite-muscovite subfacies of the Abukuma-type cordierite-amphibolite facies.

The formation of cummingtonite is generally considered to be the result of compositional changes of common hornblende according to the following formula:

$$\text{Tschermak's Molecule} + \text{quartz} \rightleftarrows \text{anorthite} + \text{cummingtonite} + \text{water}$$

Cummingtonite only forms easily when free quartz is present while plagioclase becomes richer in anorthite (Shido, 1958).

Table 14 shows that in the Galiñeiro area cummingtonite is indeed almost restricted to the (quartz-bearing) para-amphibolites (group 4 in ch. IV). The anorthite content of plagioclase in these rocks is higher than that in other amphibolites. The colour of associated hornblende is generally lighter than that in cummingtonite-free rocks. It is not understood why cummingtonite is absent in amphibolites of group 3.

TABLE 19 *Rubidium-Strontium ages of hercynian granites*

Source rock	Authors	Material	Age in 10^6 years
Coarsely porphyritic biotite granite Castro Daire, N Portugal	Bonhomme et al., 1961	Biotite	282 $\pm$ 7
Coarsely porphyritic biotite granite Serra do Marão, N Portugal	Priem et al., 1964	Whole rock Muscovite	262 $\pm$ 26 285 $\pm$ 9 } average age 283 $\pm$ 9
Coarse-grained biotite granite Berlenga Island, Portugal	Priem et al., 1965	Whole rock	280 $\pm$ 15
Coarse-grained biotite granite Traba, La Coruña, Spain	Priem et al., 1965	Whole rock Biotite	274 $\pm$ 11 305 $\pm$ 15
Porphyritic biotite granite Castredo, Lugo, Spain	Capdevila & Vialette, 1965	Biotite	276 $\pm$ 10
Two-mica granite Sta Marina, Lugo, Spain	Capdevila & Vialette, 1965	Biotite Muscovite	276 $\pm$ 9 301 $\pm$ 8

The phase of metamorphism that yielded at least the greater part of the now visible mineral assemblage was late- to post-kinematic: crystals are undeformed, the younger ones even unoriented or oriented oblique to the hercynian schistosity. Rotated crystals were never seen.

The temperature range of formation of the dark mineral assemblage of the riebeckite gneisses (550°–600° C), discussed in the section riebeckite gneiss of this chapter, lies well within the range determined for paragneiss and amphibolite; the minerals of the northeastern orthogneiss complex are relatively insensitive to small changes in metamorphic conditions and consequently did not present specific information about them.

Though several isotopic age determinations were made of hercynian metamorphic minerals (table 20), they unfortunately did not assist in establishing the *age* of the main phase of hercynian metamorphism. As stated in the section on riebeckite gneiss, petrologic evidence indicates that the megacrystal and two-mica granites intruded after or late during the main phase of regional metamorphism. The metamorphic minerals must therefore be contemporaneous with or older than these granites. Age determinations of the megacrystal granites have not yet been attempted. That of muscovite from two-mica granite of Guitiriz (Capdevila & Vialette, 1965; this paper, table 19) indicates that this granite crystallized at least 300 m.y. ago. As a consequence, the main phase of metamorphism should also be placed at least 300 m.y. ago. The biotite and microcline used for age determinations were obviously rejuvenated. Jäger (1962) draws the attention to the fact that above 300° C, biotite loses its radiogenic Sr. Apparently microcline behaves in a similar way. The fact that most biotite and microcline ages agree well with those of late- to post-hercynian biotite granites, demonstrates that only after the intrusion of these granites the temperature fell and stayed definitively below 300° C.

TABLE 20 *Rubidium-Strontium ages of gneisses and schist*

Source rock	Authors	Material	Age in 10^6 years
Micaschist of Villalba Rabade, Lugo, Spain	Capdevila & Vialette, 1965	Biotite	293 ± 17
Biotite orthogneiss E of Vigo, Spain	Priem et al., 1966	Whole rock Biotite	500 ± 25 292 ± 15
Lepidomelane- and astrophyllite-bearing riebeckite gneiss S of La Guia, Vigo, Spain	Priem et al., 1966	Whole rock Astrophyllite Lepidomelane Microcline	486 ± 24 544 ± 16 277 ± 14 278 ± 14

THE PRE-HERCYNIAN INTRUSIVE SERIES

On foregoing pages it has been demonstrated that riebeckite gneisses, northeastern orthogneisses and several types of amphibole-biotite rock and associated gneiss have igneous origins. Moreover, isotopic age determinations (table 20) point out that the pre-basic-dyke orthogneiss and post-basic-dyke riebeckite gneiss differ relatively little in age. It has not been proved, however, that all pre-hercynian granitegneisses present in the investigated area are comagmatic.

The relations between riebeckite gneiss, most igneous types of amphibole-biotite rock and some NE orthogneisses (a.o. Mosende gneiss), all being post-basic-dyke intrusives, strongly suggest this. The fact that several pre-basic-dyke orthogneisses contain green amphiboles with a more or less pronounced ferrohastingsitic character is suggestive of a certain alkaline tendency in them too. A geochemical investigation of the different rocks will probably be the best method to establish their relationship.

It is possible that the metamorphosed gabbro relics, described as amphibole-biotite rocks, belong to the same sequence: as stated in the last paragraph of the section on riebeckite gneiss, post-Cambrian gabbro is found near Alter Pedroso, SE Portugal. This gabbro has been intruded by per-alkaline syenite, locally with the formation of a kind of intrusive breccia (Teixeira & Torre de Assunção, 1957). The occurrence of fragmented gabbro in both the Portuguese and the Galician complex may be more than haphazard!

Since virtually uninterrupted sequences of Lower Paleozoic sediments E and S of Galicia prove that the caledonian orogeny is unknown on the Iberian peninsula (e.g. Stille, 1927), the pre-hercynian igneous rocks described in this paper were present at the beginning of the hercynian orogeny as a complex of alumina-saturated two-feldspar granites, partly with alkaline tendencies, of per-alkaline hypersolvus granite, and of a hybrid series varying from gabbro to ferrohastingsite-bearing biotite hypersolvusgranite.

Such complexes are also well-known in N Nigeria (a.o. Jacobson et al., 1958), Niger (a.o. Raulais, 1960; Rocci, 1960b; Fabriès & Rocci, 1965) and New Hampshire, U.S.A. (a.o. Greenwood, 1951). The Carn Chuinneag orthogneiss complex in Scotland (Harker, 1962) is metamorphosed and very similar to that in the present area.

Until recently publications presenting concrete data on the genesis of acid per-alkaline rocks were very scarce. Opinions varied from differentiation of alkali olivine-basalt via that of alumina-saturated granite to metasomatic alkalization of normal granites and other rocks.

Work carried out in the Geophysical Laboratory of the Carnegie Institution, Washington, lastly by Bailey and Schairer, provided very useful data. One of the results of their investigation of the system Na_2O-Al_2O_3-Fe_2O_3-SiO_2 is the discovery of a quaternary eutectic (quartz + albite + acmite + sodium disilicate + liquid) in the silica-saturated portion of the system (Bailey & Schairer, 1966) [1]). The compositions of natural pantellerites point to the existence of a similar alkalisilicate-rich eutectic in nature. Acid per-alkaline liquids may therefore be the residual liquids of a fractionally crystallizing alkaline magma. This explanation, however, poses the problem of the enormous but on the continents always unseen, quantities of basic primary alkali basalt magma necessary for the generation of a small quantity of residual magma. Bailey and Schairer emphasize the fact that a liquid of eutectic composition, apart from being residual, can also be the first to form in the case of partial melting of crystalline rock of appropriate composition.

[1]) Most data were published in the successive Annual Reports of the Laboratory; a paper by Bailey & Schairer on the system mentioned will appear in the Journal of Petrology, probably the February 1966 issue. Prof. Bailey was so kind as to provide the present author with a part of his manuscript, which forms the basis of the considerations regarding the origin of per-alkaline liquids in this paper.

Taking into account the occurrence of per-alkaline rhyolites in intra-oceanic provinces, where sialic contamination is impossible, as well as the abundance of per-alkaline rocks in more stable continental areas, they suggested that the primitive granite of the non-orogenic zones is per-alkaline and originated by partial melting in the lower crust or below the crust. Associated alumina-saturated types would be the result of sialic contamination during the rise of the magma along faults.
Bailey (1964) mentions a relief of pressure in the lower crust as a possible cause of partial melting. This relief could be brought about by crustal upwarping, as has been active along the east and central African rift zones. It should be mentioned that Korzhinskii (1960), though employing a widely different vocabulary and way of approach, also arrives at the conclusion that abyssal magmas are alkaline.

The Iberian peninsula was not part of a really stable continental area in the Lower Ordovician: in its southwestern half the sardic folding phase had been active in Upper Cambrian times (Capdevila, 1966), but Galicia probably just missed being influenced by that phase.
Stratigraphic evidence (see last paragraph of section riebeckite gneiss) led Teixeira & Torre de Assunção (1957) to date the intrusion of the per-alkaline rocks of SE Portugal between Silurian [1]) and Upper Westphalian, i.e. after the sardic phase of folding. Though they are younger, these rocks and their Galician analogues probably have identical origins; the associated alumina-saturated gneissified granites of Portalegre and Crato are not yet proved to be related with the Portuguese per-alkaline rocks.
Whether the compression of the sardic phase caused upwarping that led to partial melting in the lower crust, or bears no direct relation with the generation of the per-alkaline magma, posterior tensional stresses being responsible for it instead, is not clear from the available data.
The fault, that facilitated intrusion of megacrystal granites in the hercynian orogen (fig. 1), might have existed already before. There are indications that this fault is one of a system of fundamental faults; in that case it is possible that the per-alkaline magma could intrude along them.

The pre-hercynian granite-gneisses constitute a very characteristic complex of rocks in the hercynian orogen of the western Iberian peninsula. It is to be doubted whether their metasedimentary country-rocks are very different in age when compared with metasediments outside the "Complejo Antiguo" as defined by Parga-Pondal (1956).
At the geological congress in Santiago de Compostela ("Reunion sobre geologia de Galicia y norte de Portugal", 1965) a proposal has been accepted to redefine the term and to consider in future only t h e c o m p l e x o f p r e - h e r c y n i a n, m a i n l y a c i d, i g n e o u s r o c k s a s "C o m p l e j o A n t i g u o".

Apart from the last two, the sections of this chapter followed the history of each rock group individually. Mutual relations, etc. were only discussed where necessary. Plate 3 represents a synoptic table in which a proper place has been assigned to all rocks and events, as far as could be deduced from the presented data.

[1]) See note, p. 163.

SUMMARY

In the investigated area pre-hercynian schistose mica-rich gneisses and planar or planolinear, foliated feldspar-rich gneisses were found, both intruded by several types of hercynian granite.

The mica-rich gneisses contain plagioclase, quartz and biotite as major constituents; as minor constituents, not in all rocks, a.o. muscovite, cordierite, andalusite and garnet. Their composition and its strongly varying character, often visible as a banding are an indication of sedimentary origin: the mica-rich gneisses are paragneisses.

Elongated quartz grains and small flakes of biotite sometimes occur in these gneisses as helycitic inclusions within plagioclase and cordierite, that have a metablastic habit. Since the metablasts never enclose the hercynian schistosity, present outside these minerals, they must have grown early in the hercynian history, which renders a pre-hercynian age of the enclosed minerals (apart from quartz and biotite: turbid and often resorbed garnet) probable. As evidenced by the formation of garnet in these paragneisses, the pre-hercynian metamorphism has been of the Barrovian type.

Folded schistosity may be observed regularly in the paragneiss; in feldspar-rich gneiss, however, folded folation is an extremely rare phenomenon. Against feldspar-rich gneiss in the NE of the area a fine-grained, cordierite-bearing type of paragneiss is present with some thermometamorphic properties: cordierite in it is altered, non-metablastic and older than metablastic plagioclase; very fine banding is often visible. Part of the feldspar-rich gneiss complex has a per-alkaline composition and contains a.o. riebeckite, aegirine and astrophyllite.

The characteristics listed above, among others, made clear that the complex of feldspar-rich gneiss represents an intrusive body, younger than the surrounding paragneiss.

Since the intrusive granitic rocks exerted thermometamorphic influence upon paragneiss and the intrusion therefore cannot have taken place at great depth, pre-hercynian regional metamorphism and intrusion of the granite complex cannot have been contemporaneous. This is supported by the observation that pre-hercynian garnet is relatively rare in the thermometamorphic part: probably it has been broken down during this metamorphic period. Regional metamorphism must therefore be older than the thermometamorphism. Whole-rock Rb-Sr age-determinations of a riebeckite gneiss and a biotite gneiss yielded ages around 500 m.y., i.e., that of the base of the Ordovician. There are no indications that Galicia has been influenced by the assyntian phase of folding, from which has to be concluded that the pre-hercynian metamorphism has a Precambrian age.

The hercynian orogeny caused a new schistosity in paragneiss, principally indicated by biotite, quartz and muscovite, always outside the metablastic minerals. The occurrence of cordierite and andalusite in the paragneiss on a regional scale and the presence of cummingtonite in quartz-bearing basic lenses proves that the hercynian metamorphism, in contrast with the pre-hercynian, has been of the Abukuma-type. From the generally undeformed habit of the minerals it follows that hercynian metamorphism outlasted deformation.

The ancient granite complex was modified by the hercynian orogenesis into blasto-

mylonitic gneiss. Originally K-feldspar megacrystal-bearing granites are at present exposed as augengneiss.

The granite-gneisses could be easily separated into the following types:
1. Biotite gneisses with compositions varying from granodioritic to alkaligranitic and with occasionally green amphibole or muscovite in addition to biotite as a dark constituent, occupy a larger area than the other types (Northeastern orthogneiss complex).
2. The aegirine-riebeckite gneiss, already mentioned above, which is — as far as known at present — the most notable occurrence of acid per-alkaline gneiss in the world.
3. Amphibole-biotite rocks and gneisses constitute a third, very heterogeneous group. In the field basic rocks were found enclosed as fragments in more acid rocks. It is thought that the different types of this group originated through contamination of an alkaline or per-alkaline granitic magma with earlier intruded gabbroic rock.

Amphibolite lenses with clear relict structures of hypabyssal rocks were found within and around the granite-gneisses, but are lacking a.o. in per-alkaline gneiss and amphibole-biotite rock and gneiss. Intrusion of basic dykes must therefore have interrupted that of the granitic rocks.
In many cases it turned out to be possible to discriminate between amphibolites with an igneous and those with a sedimentary origin.

During the hercynian orogenesis reaction took place between per-alkaline and neighbouring rocks resulting in metasomatic transport of sodium an some potassium from the former into the latter: Around aegirine-riebeckite gneiss a clear concentration of late-hercynian albite and, though less commonly, of microcline has been observed.
A group of rocks situated between aegirine-riebeckite gneiss and igneous amphibole-biotite rock and gneiss, NNE of the Galiñeiro, seems to have originated through metasomatic influence of the per-alkaline rock on paragneiss, both at its intrusion and during the hercynian metamorphism.

N-S trending strikes of schistosity and foliation predominate, especially in the northern half of the area. Recumbent isoclinal folds with N-S trending axes are not rare in outcrops of paragneiss. Since structures, apart from aplites, quartz veins and basic dykes were absent in the ancient granites, folds (with subhorizontal N-S trending axes) are only visible in the latter bodies, not in the granite-gneisses themselves.
The orientations of foliation planes in the granite-gneisses demonstrate the existence of some large-scale structures with N-S axes, slightly curved around E-W trending axes.
Large faults have approximately NW-SE strikes. Movements along them seem to have taken place in a vertical and in a horizontal (dextral) sense. They clearly influenced dip and strike of schistosities and foliations of adjacent rocks.

Hercynian megacrystal, muscovite, two-mica and coarse-grained biotite granites intruded into the metamorphic complex after the main phase of metamorphism and in the given order. Migmatitic rocks are completely lacking.
Megacrystal granites with associated muscovite granite and other differentiation products are common in Galicia, generally along fault-zones; they show magmatic characteristics. From the relations between metamorphic recrystallization, fault movement and thermometamorphic influence of the megacrystal granite it could be deduced that it intruded during a period of N-S compression. The magma probably derives from deep levels of the hercynian orogen.
Two-mica granites are also clearly intrusive in the studied area. They are considered

to be young, strongly homogenized and allochthonous representatives of the hercynian anatectic cycle.
Coarse-grained biotite granite is the youngest hercynian granite, Upper Carboniferous to Lower Permian in age. The bodies are mostly oval or circular. The intrusion of these granites is ascribed to subcrustal cauldron subsidence. The great similarity between megacrystal and coarse-grained biotite granite suggests that both granites derive from comparable magma chambers.
Narrow dykes and small bodies of cordierite-quartzdiorite and associated granodiorite or granite do not have contacts with other granite, leaving their relative ages uncertain. Contrary to above-mentioned granites, they were not found outside the investigated area. Their properties point to an anatectic origin, probably not very far below the present erosion surface.

SAMENVATTING

In het onderzochte gebied zijn pre-hercynische schisteuze glimmergneizen en planaire en planolineaire, gefolieerde veldspaatrijke gneizen, beide geintrudeerd door diverse typen hercynische graniet aangetroffen. De glimmergneizen bevatten als hoofdbestanddelen plagioklaas, kwarts, biotiet en als nevenbestanddelen, niet in alle gesteenten, o.a. muscoviet, cordieriet, andalusiet en granaat. Hun samenstelling en het sterk wisselende karakter ervan, dat vaak als banding tot uiting komt, zijn aanduidingen van een sedimentaire herkomst: de glimmerrijke gneizen zijn paragneizen.
Langgerekte kwartskorrels en fijne schubjes biotiet komen in deze gneizen soms voor als helycitische insluitsels in plagioklaas en cordieriet, die een metablastische habitus vertonen. Daar de metablasten de buiten deze mineralen zichtbare hercynische schistositeit nooit insluiten moeten zij vroeg-hercynisch zijn gegroeid, waardoor het waarschijnlijk wordt dat de mineralen die ingesloten zijn een pre-hercynische ouderdom hebben. Hiertoe behoort naast kwarts en biotiet de — troebele en vaak geresorbeerde — granaat. De pre-hercynische metamorfose was, getuige de vorming van granaat in deze paragneizen, van het Barrow-type.

Geplooide schistositeit kan in de paragneiss geregeld worden waargenomen; in de veldspaatrijke gneis, daarentegen, is geplooide foliatie een uiterst zeldzaam verschijnsel. Tegen veldspaatrijke gneis in het noordoosten van het gebied is in de paragneis een fijnkorrelig, cordieriethoudend type aanwezig, dat kenmerken van thermometamorfose vertoont: de cordieriet erin is omgezet, niet metablastisch en ouder dan metablastische plagioklaas; zeer fijne banding is vaak zichtbaar. Een deel van het veldspaatrijke gneiscomplex heeft een per-alkalische samenstelling en bevat mineralen als riebeckiet, aegirien en astrophylliet.
O.a. deze kenmerken hebben tot de hypothese geleid, dat het complex van veldspaatrijke gneis een intrusief lichaam is, jonger dan de omringende paragneis.

Daar de intrusieve granitische gesteenten op de paragneis thermometamorfe invloed uitoefenden en de intrusie dus niet op grote diepte plaats vond, kunnen pre-hercynische regionale metamorfose en intrusie van het granietcomplex niet even oud geweest zijn. Dit blijkt ook uit het feit, dat pre-hercynische granaat in het thermometamorf beinvloede gedeelte van de paragneis relatief zeldzaam is. Het is waarschijnlijk tijdens deze metamorfose afgebroken. De regionale metamorfose moet derhalve vroeger dan de thermometamorfose hebben plaatsgevonden. Absolute ouderdomsbepalingen met behulp van Rb en Sr isotopen gaven voor een riebeckiet-

gneis en een biotietgneis vormingsouderdommen van ongeveer 500 miljoen jaar, d.w.z. die van de basis van het Ordovicium. Er zijn geen aanwijzingen dat Galicië door de assyntische plooiingsfase is beinvloed, waardoor geconcludeerd moet worden dat de pre-hercynische metamorfose een Precambrische ouderdom heeft.

In de paragneizen ontstond tijdens de hercynische orogenese een nieuwe schistositeit, voornamelijk aangeduid door biotiet, kwarts en muscoviet, steeds buiten de metablastische mineralen. Het voorkomen van cordieriet en andalusiet op regionale schaal in de paragneis en de aanwezigheid van cummingtoniet in kwartshoudende basische lenzen wijst erop, dat de hercynische metamorfose, in tegenstelling tot de pre-hercynische, van het Abukuma-type is geweest. De in de regel ongedeformeerde habitus van de mineralen toont aan dat de metamorfose langer heeft geduurd dan de deformatie.

Het oude granietcomplex werd tijdens de hercynische orogenese veranderd in gneis met een mylonitische textuur. Granieten, die oorspronkelijk kaliveldspaatmegakristen bevatten, zijn nu als ogengneis ontsloten.

Verschillende duidelijk te onderscheiden typen granietgneis komen voor:

1. Biotietgneis met een samenstelling varierend van granodioritisch tot alkaligranitisch en met naast biotiet soms groene amfibool of muscoviet als donker bestanddeel, neemt verreweg het grootste oppervlak in (Noordoostelijk orthogneis complex).
2. De reeds genoemde aegirien-riebeckietgneis. Het is, voor zover thans bekend, het fraaiste voorkomen van zure per-alkalische gneis in de wereld.
3. Amfibool-biotietrotsen en -gneizen vormen een derde onderdeel van het granietgneis complex. Het is een zeer heterogene groep van gesteenten. In het veld werden basische gesteenten als fragmenten ingesloten gevonden in zuurdere typen. Aangenomen wordt dat zij ontstonden door contaminatie van een alkali- of per-alkaligranitisch magma met eerder geintrudeerd gabbroid gesteente.

Amfibolietlenzen met duidelijke relictstructuren van ganggesteenten werden in en om de granietgneizen gevonden maar ontbreken o.a. in de per-alkalische gneis en amfibool-biotietrots en -gneis. Intrusie van basische gangen moet dus die van de granitische gesteenten hebben onderbroken.

Het bleek in het onderzochte gebied in veel gevallen mogelijk amfibolieten ontstaan door metamorfose van basische gangen te onderscheiden van die, welke uit kalkrijke banden of lenzen in de paragneis werden gevormd.

Tijdens de hercynische orogenese vond reactie plaats tussen de per-alkalische en omgevende gneizen, voornamelijk tot uiting komend als metasomatische afvoer van natrium en kalium uit de eerste. Om de aegirien-riebeckietgneis is een duidelijke concentratie van laatgevormde albiet en, zij het in mindere mate, van mikroklien waargenomen.

Een tussen aegirien-riebeckietgneis en amfibool-biotietrots en -gneis gelegen groep gesteenten NNE van de Galiñeiro lijkt metasomatisch te zijn ontstaan door invloed van per-alkalisch gesteente op paragneis, zowel bij de intrusie als tijdens de hercynische metamorfose.

N-S gerichte strekkingen van schistositeit en foliatie overheersen, vooral in het noordelijk deel van het gebied. In de zuidelijke helft is het beeld verwarder. In paragneisontsluitingen zijn liggende isoklinale plooien met N-S assen niet zeldzaam. De granietgneislichamen bezaten geen voortekening, waardoor plooien niet zichtbaar werden; wel zijn ingesloten apliet-, kwarts- en amfibolietlichamen om N-S assen geplooid.

De foliatierichtingen van de granietgneizen wijzen op het bestaan van enkele structuren met grote amplitude en N-S gerichte assen, die zwak om E-W assen zijn gebogen.

Grote breuken hebben ongeveer een NW-SE strekking. Er zijn aanwijzingen, dat de beweging erlangs zowel in horizontale als in verticale richting heeft plaatsgevonden. Ze hebben helling en strekking van schistositeiten en foliaties duidelijk beïnvloed.

Hercynische megakristen, muscoviet, tweeglimmer en grofkorrelige biotietgranieten zijn intrusief in het metamorfe complex. Hun intrusie vond plaats na de hoofdfase van de metamorfose en wel in genoemde volgorde. Migmatische gesteenten ontbreken in het onderzochte gebied geheel.
Megakristengranieten met geassocieerde muscovietgraniet en andere differentiatieproducten komen elders in Galicië ook veelvuldig voor, steeds langs breukzones; ze hebben een magmatisch karakter. Uit de relaties tussen metamorfe rekristallisatie, breukbeweging en thermometamorfe invloed van de megakristengraniet kon worden afgeleid dat hij intrudeerde tijdens een periode van N-S compressie. Het magma is waarschijnlijk afkomstig uit diepe delen van het hercynisch orogeen.
Ook de tweeglimmergranieten zijn in het onderzochte gebied duidelijk intrusief. Zij worden beschouwd als jonge, sterk gehomogeniseerde, allochthone vertegenwoordigers van de hercynische anatectische cyclus.
Grofkorrelige biotietgraniet is de jongste hercynische graniet, met Boven-Carbonische tot Onder-Permische ouderdom. De lichamen zijn meestal ovaal tot rond. Hun intrusie wordt wel toegeschreven aan het inzakken van ringvormige delen van de bovenste aardkorst tijdens een rekperiode, waarna de graniet de opengekomen plaatsen heeft ingenomen. De verregaande mineralogische gelijkenis tussen megakristengraniet en grofkorrelige biotietgraniet doet vermoeden dat beide uit vergelijkbare magmahaarden konden omhoogkomen.
Smalle gangen en kleine lichamen van cordieriet kwartsdioriet, tweeglimmergranodioriet en -graniet hebben geen contacten met andere granieten waardoor relatieve datering onmogelijk is. In tegenstelling tot bovengenoemde granieten zijn zij niet buiten het onderzochte gebied waargenomen. De eigenschappen van de gesteenten duiden op een anatektische oorsprong, waarschijnlijk niet ver onder het huidige aardoppervlak.

RESUMEN

En la zona investigada se han encontrado gneises micáceos esquistosos y gneises feldespáticos, foliados, con texturas planares y planolineares. Los dos son anteherciniаnos y fueron invadidos por varios tipos de granito herciniano.

Los gneises micáceos contienen como minerales principales: plagioclasa, cuarzo, biotita y, en cantidades menores, ausentes en parte de las muestras, entre otros: muscovita, cordierita, andalusita y granate. La composición de los gneises y su carácter variable, manifestándose muchas veces como estructura bandeada, indican su origen sedimentario: los gneises micáceos son paragneises.
En estos gneises, granos alargados de cuarzo y escamas finas de biotita ocurren a veces como inclusiones helicíticas en plagioclasa y cordierita con hábito metablástico. Como los metablastos nunca incluyen la esquistosidad herciniana, que solo se encuentra fuera de estos minerales, deben de haber crecido en la orogenia herciniana temprana, que hace suponer más bien una edad ante-herciniana de los minerales incluidos en los metablastos (aparte de cuarzo y biotita fina: granate turbio y reabsorbido). La metamorfosis ante-herciniana fue del tipo "Barrow", ya que ha habido formación de granate en estos gneises.

Una esquistosidad plegada es visible frecuentemente en el paragneis; en el gneis feldespático, en cambio, una foliación plegada es un fenómeno sumamente raro. Contra los gneises feldespáticos en el NE de la región aflora un tipo de paragneis de grano fino y de tipo cordieritífero, que tiene características termometamórficas: la cordierita está alterada, no metablástica y de origen anterior a la plagioclasa metablástica; una laminación muy fina es muchas veces visible. Parte del complejo de gneises feldespáticos tiene una composición per-alcalina y contiene minerales como: riebeckita, aegirina y astrofilita.
Las propiedades citadas han llevado a la hipótesis, de que el complejo de gneises feldespáticos es un cuerpo intrusivo, más joven que los paragneises circundantes.

Como las rocas graníticas intrusivas han ejercido sobre los paragneises una influencia termometamórfica, y por consiguiente la intrusión no tuvo lugar a gran profundidad, el metamorfismo regional ante-herciniano y la intrusión del complejo granítico no pueden haberse efectuado en una y la misma época. Esto resulta también de la observación de que el granate ante-herciniano es relativamente escaso en la parte termometamórfica. Probablemente el mineral se hizo inestable en la aureola de contacto y por consecuencia ha sido alterado. El metamorfismo regional debe de haber precedido a la termometamorfosis. De las determinaciones de edad absoluta con isotopos Rb-Sr en gneis de riebeckita y otro de biotita han resultado edades de formación de unos 500 millones de años, o sea, aproximadamente de la base del Ordoviciano. No hay indicios de que Galicia fuera influenciada por la fase orogénica assyntica. Por eso, parece lógica la conclusión de que la metamorfosis ante-herciniana es de edad Precámbrica.

En los paragneises originó durante la orogenia herciniana una nueva esquistosidad, principalmente indicada por biotita, cuarzo y muscovita, siempre fuera de los minerales metablásticos. La existencia de cordierita y andalusita en escala regional en los paragneises y la presencia de cummingtonita en unas rocas básicas cuarzíferas indican que el metamorfismo herciniano, contrario al ante-herciniano, ha sido del tipo "Abukuma". El hábito generalmente no deformado demuestra que la recristalización metamórfica ha durado más tiempo que la deformación.
El Complejo Antiguo Granítico se transformó en gneis con textura milonítica. Los granitos que anteriormente contenían megacristales de feldespato potásico, afloran ahora como gneises glandulares blastomiloníticos.

Se pueden distinguir varios tipos de gneis granítico:
1. El gneis de biotita ocupa la mayor superficie de los afloramientos de gneises graníticos (Complejo ortognéisico del Nordeste). La composición varía de granodiorítica a alcaligranítica; aparte de la biotita siempre presente, el gneis contiene amfibol verde o muscovita como mineral "oscuro".
2. El gneis de aegirina y riebeckita, ya mencionado. Según se sabe hasta la fecha, es el mayor afloramiento de gneis per-alcalino ácido en el mundo entero y el más bonito.
3. Rocas y gneises con amfibol-biotita constituyen un tercer elemento del complejo granito-gnéisico. Sobre el terreno se hallaron fragmentos de rocas básicas englobados por tipos más ácidos. Suponemos que se habrán originado por contaminación de un magma granítico alcalino o per-alcalino con material gabroide penetrado anteriormente.

Cuerpos lenticulares de amfibolita con estructuras relictas de rocas filonianas fueron encontrados en gneises graníticos y en su derredor, pero faltan, entre otros, en el gneis per-alcalino y en la roca y gneis de amfibol-biotita. La intrusión de filones básicos debe de haber interrumpido la de las rocas graníticas.

En muchos casos fue posible distinguir entre amfibolitas de origen intrusivo y otras de origen sedimentario.

Durante la orogenia herciniana una reacción tuvo lugar entre el gneis per-alcalino y los gneises vecinos, habiendo de aquél a éstos un transporte metasomático de sodio y algo de potasio: alrededor de los gneises de aegirina y riebeckita hay una concentración clara de albita de formación tardía y — en menor grado — de microclina.
Un grupo de rocas, situado entre el gneis per-alcalino y las rocas y gneises de amfibol-biotita al NNE del Galiñeiro, parece haberse formado por influencia metasomática del gneis per-alcalino sobre el paragneis, tanto en la época de la intrusión como durante la metamorfosis herciniana.

Predominan las esquistosidades y foliaciones con rumbo N-S, especialmente en la parte norte de la región. No son raros los pliegues isoclinales con plano de simetría subhorizontal y ejes N-S. Los cuerpos graníticos antiguos no contenían estructuras planares (aparte de diques de aplita, cuarzo y roca básica). Por consecuencia, no aparecen pliegues en los gneises graníticos sino en los cuerpos mencionados entre paréntesis.
Las orientaciones de la foliacíon de los gneises graníticos indican la existencia de unas estructuras de gran amplitud y ejes N-S, ligeramente plegadas sobre ejes E-W. Unas grandes fallas tienen un rumbo NW-SE. Hay indicios de que el movimiento tuvo lugar en dirección vertical y horizontal (dextral). Han influido notablemente en las orientaciones de esquistosidad o foliación en rocas vecinas.

Granitos hercinianos de megacristales, de muscovita, de dos micas y de grano grueso de biotita son intrusivos en el complejo metamórfico. La intrusión fué posterior a la fase principal del metamorfismo. Rocas migmatíticas faltan por completo.
Granitos de megacristales con granito de muscovita y otros productos de diferenciación ocurren frecuentemente en Galicia, siempre a lo largo de fallas importantes; son de carácter magmático. Fué posible deducir de las relaciones entre la recristalización metamórfica, el movimiento de fallas y la influencia termometamórfica del granito de megacristales, que este último se introdujo durante un período de compresión norte-sur. El magma probablemente proviene de partes profundas del orogenio herciniano.
Los granitos de dos micas son también claramente intrusivos en la zona investigada. Son considerados como los representantes más jóvenes, fuertemente homogenizados y alóctonos del ciclo anatéctico herciniano.
El granito de grano grueso de biotita es el granito herciniano más joven, con edad entre Carbonífero Superior y Pérmico Inferior. Los plutones son generalmente de forma circular u óvala. La intrusión parece atribuible al hundimiento de fosas tectónicas circulares y al relleno de los espacios creados por magma granítico.
La semejanza entre granito de megacristales y granito de grano grueso de biotita hace suponer que los dos han surgido de recipientes magmáticos comparables.
Diques estrechos y cuerpos pequeños de cuarzodiorita de cordierita con granito de dos micas y granodiorita asociados no tienen contactos con otros granitos; por consecuencia la edad relativa queda incierta. Contrario a los granitos mencionados arriba no se observaron fuera de la zona investigada. Las propiedades de estas rocas son indicativas de un origen anatéctico, no muy inferior al actual nivel de erosión.

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APPENDIX

Localities of specimens mentioned in text

(in degrees, minutes and seconds)

Sample number	Longitude (W of Madrid)			Latitude			Quadrant (see p. 10)	Sample number	Longitude (W of Madrid)			Latitude			Quadrant (see p. 10)
15	4	58	25	42	9	22	261–C1	416	4	59	20	42	10	3	223–C4
16	4	58	53	42	9	27	261–C1	417	4	59	20	42	10	3	223–C4
20	5	0	15	42	9	40	261–C1	420	4	59	53	42	10	20	223–C4
21	5	0	22	42	9	43	261–C1	421	4	59	45	42	10	17	223–C4
49	5	1	54	42	8	42	261–C1	423	4	59	25	42	10	2	223–C4
67	4	59	58	42	8	14	261–C1	430	4	59	29	42	9	54	261–C1
87	5	0	50	42	8	47	261–C1	431	4	59	29	42	9	54	261–C1
150	5	2	0	42	8	45	261–BC1	433	4	59	0	42	9	28	261–C1
154	4	58	52	42	8	47	261–C1	445	4	57	23	42	11	40	223–D4
173	4	59	30	42	9	24	261–C1	446	4	57	52	42	11	50	223–D4
175	4	59	27	42	9	23	261–C1	447	4	58	8	42	12	37	223–C3
194	4	59	50	42	10	28	223–C4	448	4	58	32	42	12	44	223–C3
195	5	0	5	42	10	7	223–C4	449	4	58	32	42	12	44	223–C3
197	4	59	54	42	9	43	261–C1	453	4	58	52	42	8	47	261–C1
200	4	59	42	42	9	37	261–C1	461	5	1	2	42	14	58	223–C3
201	4	59	41	42	9	37	261–C1	489	5	0	47	42	10	17	223–C4
204	4	59	55	42	10	8	223–C4	504	S of Mt. Zorro, outside						
205	4	59	55	42	10	8	223–C4		area						261–C2
215	4	59	52	42	9	43	261–C1	506	4	59	58	42	7	23	261–C2
216A	5	0	0	42	9	55	261–C1	508A	4	59	58	42	7	18	261–C2
221	4	59	58	42	9	55	261–C1	514	5	2	40	42	10	18	223–B4
224	5	0	40	42	8	3	261–C1	524	5	2	50	42	10	27	223–B4
229	5	0	34	42	11	15	223–C4	529	5	2	30	42	9	56	261–B1
233	4	58	58	42	8	20	261–C1	530	5	0	22	42	10	50	223–C4
254	5	0	30	42	9	13	261–C1	542	4	58	10	42	7	55	261–C1
261	5	0	22	42	9	12	261–C1	551	5	30	0	42	9	9	261–C1
264	4	59	32	42	7	40	261–C1	552	5	1	2	42	9	9	261–C1
269	5	1	3	42	8	12	261–C1	557	5	0	47	42	7	42	261–C1
270	5	1	3	42	8	12	261–C1	568	4	59	56	42	8	16	261–C1
271	5	1	0	42	8	0	261–C1	576	5	0	53	42	15	36	223–C2
316	4	58	57	42	9	33	261–C1	583	4	59	58	42	8	20	261–C1
317	4	58	36	42	9	24	261–C1	584	4	59	58	42	8	20	261–C1
350	4	58	47	42	9	17	261–C1	587	4	57	47	42	13	56	223–D3
353	4	58	58	42	9	0	261–C1	591	4	58	38	42	14	12	223–C3
363	5	0	48	42	7	47	261–C1	592	4	59	27	42	14	18	223–C3
364	5	0	48	42	7	47	261–C1	593	4	59	27	42	14	18	223–C3
392	5	1	9	42	9	0	261–C1	594	4	59	40	42	14	18	223–C3
395	5	1	53	42	8	45	261–C1	596	5	0	7	42	13	53	223–C3
396	5	1	57	42	8	47	261–C1	597	5	0	7	42	13	53	223–C3
398	4	59	22	42	9	42	261–C1	599	4	59	45	42	15	27	223–C2
399	4	59	23	42	9	48	261–C1	602	5	0	10	42	15	18	223–C2
402	4	59	23	42	9	47	261–C1	604	4	56	14	42	14	6	223–D3
403	4	59	23	42	9	47	261–C1	605	4	56	14	42	14	6	223–D3
404	4	59	23	42	9	48	261–C1	611	Loose block, SW Vigo						223–B3
415	4	59	20	42	9	58	261–C1	612	5	2	38	42	13	21	223–B3

Sample number	Longitude (W of Madrid)			Latitude			Quadrant (see p. 10)	Sample number	Longitude (W of Madrid)			Latitude			Quadrant (see p. 10)
613	4	59	7	42	12	48	223–C3	735	4	58	10	42	15	8	223–C2
614	4	59	20	42	12	57	223–C3	740C	4	59	27	42	14	33	223–C3
615	5	1	46	42	12	23	223–C4	742	4	58	50	42	14	53	223–C3
620	4	56	54	42	13	0	223–D3	744	4	58	40	42	15	10	223–C2
621	4	56	54	42	13	0	223–D3	745	4	59	5	42	15	30	223–C2
622	4	57	17	42	12	34	223–D3	747	4	57	13	42	8	54	261–D1
623	4	57	22	42	11	22	223–D4	749	4	57	53	42	8	17	261–D1
625	4	57	20	42	10	55	223–D4	750	4	57	59	42	8	3	261–D1
628	5	2	5	42	12	37	223–B3	753A	4	57	39	42	12	29	223–D4
629	5	3	14	42	9	8	261–B1	755	4	57	52	42	14	7	223–D3
632	5	2	39	42	8	58	261–B1	756	4	57	43	42	14	37	233–D3
639	5	2	15	42	12	48	223–B3	757	4	57	15	42	14	42	223–D3
640	5	2	57	42	11	59	223–B4	760	4	57	2	42	14	32	223–D3
642	5	2	39	42	12	8	223–B4	769	4	59	14	42	15	27	223–C2
649	5	3	15	42	11	20	223–B4	771A	5	1	19	42	13	28	223–C3
660	5	1	41	42	13	0	223–C3	773	5	1	19	42	13	28	223–C3
663	4	59	34	42	10	13	223–C4	780	4	58	35	42	13	32	223–C3
667	4	58	48	42	11	5	223–C4	783	4	59	8	42	12	33	223–C3
669	4	58	30	42	12	13	223–C4	786–792	5	0	22	42	15	25	223–C2
680	4	59	3	42	9	8	261–C1	795–799	5	0	53	42	9	17	223–C2
683	5	2	24	42	11	27	223–B4	801	4	57	56	42	12	47	223–D3
691A,C	4	58	50	42	12	22	223–C4	804	4	58	20	42	11	23	223–C4
695	Loose block, S of Vigo						223–B3	805	4	59	16	42	10	36	223–C4
699	5	1	2	42	14	58	223–C3	807	4	59	32	42	11	32	223–C4
705	4	57	24	42	13	35	223–D3	811–817	5	0	22	42	11	4	223–C4
710	5	1	2	42	14	58	223–C3	821	4	58	0	42	11	22	223-CD4
713	4	57	53	42	11	52	223–D4	839	5	0	9	42	7	28	261–C2
718	5	1	1	42	15	8	223–C2	854	5	2	10	42	11	12	223–B4
721	5	0	6	42	13	18	223–C3	855	5	2	14	42	11	29	223–B4
723A	5	2	21	42	13	55	223–B3	858	5	0	3	42	10	59	223–C4
728	4	56	34	42	14	50	223–D3	867	4	58	12	42	9	16	261–C1
730	4	57	0	42	14	54	223–D3	61Cor.20	5	1	2	42	14	58	223–C3
734A	4	57	38	42	15	18	223–D2								

Specimens described in chapter IV are indicated on detailed map, plate 2.