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PETROLOGY, PETROFABRICS, AND STRUCTURAL GEOLOGY OF THE SIERRA DE OUTES — MUROS REGION (PROV. LA CORUÑA, SPAIN)

BY

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CONTENTS

ABSTRACT

The petrography and the structural geology of some parts of the "Hercynian" orogene of western Galicia is discussed. The oldest rocks are metasediments and orthogneisses which have some relic-structures of an older orogeny. The "Hercynian" migmatization gave rise to a large series of anatectic granite formations. Three "Hercynian" phases of deformation, all with a WSW-ENE-directed stress-field, have been distinguished. Younger wrench-faults are originated by the same stress-field. Some fabric analyses show that the first two phases have a sub-vertical, NNW-SSE-striking schistosity, each with a horizontal B-axis, and that the third phase has a vertical N-S-striking cleavage with a vertical B'-axis. The migmatization took place after the first phase.

RESUMEN EN ESPAÑOL

Se discute la petrografía y la geología estructural de una parte del orógeno "Hercínico" en Galicia Occidental. Las rocas más viejas son metasedimentas y ortogneises, que tienen algunas estructuras relictas de una orogénesis más antigua. La migmatización "hercínica" produjo una serie larga de formaciones compuestas de granitos anatécticos. Se han podido distinguir tres fases "hercínicas" de deformación, todas con el mayor componente de stress en la dirección OSO-ENE. Fallas transversales — de rechazo horizontal — más recientes tienen su origen tambien en los mismos stresses. Algunos análisis de estructura demuestran, que las primeras dos fases tienen una esquistosidad subvertical de dirección NNO-SSE, cada una con un B-eje horizontal y que la tercera fase tiene un clivaje vertical de dirección N-S con un B′-eje vertical. La migmatización ha ocurrido después de la primera fase.

INTRODUCTION

This paper presents the results of petrographical and structural investigations carried out in the region north of the Ría de Noya y Muros, roughly between Sierra de Outes and Muros, in the province of la Coruña (Galicia, NW Spain). Some petrofabric analyses have been made. This paper is in fact an extract from an unpublished Master's thesis for the University of Leiden.

The mapping was done during the summers of 1961 and 1962, using topographical maps 93 and 119 of the Instituto Geográfico y Catastral de España on a scale of 1 : 50000 but enlarged for the mapping to a scale of 1 : 25000.

The regions N and NW of the region dealt with in this paper have been mapped by E. H. von Metzsch and W. P. F. H. de Graaff respectively (internal reports, Leiden University).

The fieldwork was done under the supervision of Professor E. den Tex, Dr. P. J. M. Ypma, and Drs. P. Floor; Drs. Floor also supervised the microscopical work.

This region is a part of the arcuate, roughly N-S-striking "migmatic infrastructure" (den Tex, 1961) of the complex orogenic belt of western Galicia. The foliation and rock boundaries in this region normally have a NNW-SSE strike. It is possible to distinguish certain groups of rock. Firstly, there is the zone between Rates and Corga which has been called the "Complejo Antiguo" (the Old Complex) by Parga Pondal (1956), who considers it to be an upthrusted slab containing the oldest rocks of Galicia. This is a narrow (1 to 15 km) but very long (roughly 120 km) arcuate zone, parallel to the mountain belt. It often contains alkaline rocks and has therefore also been called the "Alkaline gneiss group" by den Tex (1961). The region discussed in this paper does not contain such alkaline rocks, only orthogneisses and metasediments being present. The zone W of and parallel to the Complejo Antiguo is also a narrow, long belt. It contains chiefly a megacrystal biotite granite with some differentiation products. Parga Pondal (1956) calls it a trondhjemite. To the E of the Complejo Antiguo and W of the megacrystal biotite granite occur the anatectic rocks. Schists and paragneisses are migmatized. All stages of the migmatization are visible, though not always clearly: metablastic schists, metatexitic gneisses, diatexitic gneisses, diatexites, and palingenic granites. (These names are used in the same sense as in Mehnert, 1957.)

PETROGRAPHY OF THE "PRE-CAMBRIAN" METASEDIMENTS

Metasediments exclusive of para-amphibolites

This group contains two-mica paragneisses, two-mica schists, graphite schists, and quartzites. They are always fine-grained rocks (the median grain size of a rock has been classified, using the following terms and boundary values: very coarse-grained (over 3 cm); coarse-grained (5 mm—3 cm); medium-grained (1 mm—5 mm); fine-grained (under 1 mm)).

The paragneisses of the Complejo Antiguo are very variable in colour; sometimes they are darkish, biotite-rich rock, sometimes light-coloured, feldspar-rich rock with small feldspar-augen. They contain little muscovite, although the muscovite content increases to the east. Everywhere these gneisses have quartz lenses. These lenses often contain andalusite. They are perhaps metatexitic segregations. They lie parallel to the NNW-SSE-striking, sub-vertical schistosity planes. Sedimentary layering is invisible, except in some places where the paragneiss contains narrow layers of graphite schist, almost parallel to the schistosity.

It seems likely that all these gneisses are folded isoclinally. The schistosities are bent into a N-S position near the wrench-faults. In the vicinity of these faults there are many small sinistral knick-zones with vertical axes (fig. 1) which probably originated as compensation for the dextral wrench-faults. Many very small wrench-faults occur throughout the paragneiss.

On the map, a fault-line has been drawn between the Complejo Antiguo and the eastern migmatic complex (migmatic infrastructure of den Tex, 1961, or Lage-group of Parga Pondal, 1956). This fault is not visible in the field, but has been traced N and S of this region. There are, however, some arguments in favour of its

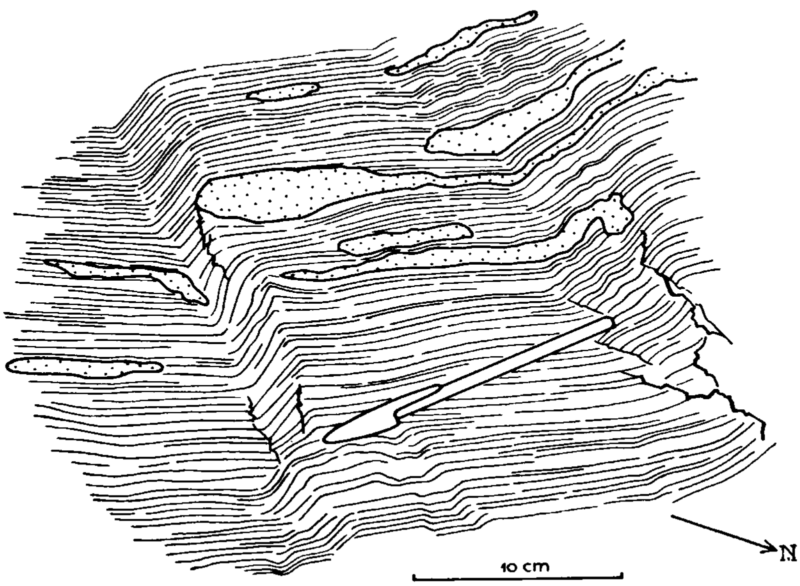

Fig. 1. Small sinistral knick-zones in the two-mica paragneiss. Quartz lenses are also bent.

presence. Firstly, there are compositional differences: two-mica gneisses west of the fault, two-mica schists on the other side. In the second place, there are many amphibolite sills and lenses in the gneisses and none in the schists. In the third place, in spite of their greater resistivity the schists are strongly migmatized, in contrast to the paragneisses. Furthermore, the schists are much richer in muscovite. To the E the schists contain more and more metatexitic, and then diatexitic, lenses and dikes. In some places the anatexis has given rise to nebulitic granites or diatexites, with only a few two-mica patches and bands.

The rocks found to the W of the megacrystal biotite granite were also grouped in the Lage-group by Parga Pondal. The village of Freijo is situated on a narrow belt of schist, only 300 to 350 m wide, which can be followed over a long distance to the NNW. This schist is composed of very dark, biotite-rich rock containing light-coloured metatexitic lenses and veins of pegmatitic material (plate III, fig. 1). On the contact between schist and metatect there are often tourmaline concentrations.

The granites in the W contain many xenoliths, mostly of two-mica schist but also of two-mica paragneisses, two-feldspar gneisses, and of magnetite-bearing quartzites. Near Abelleira the schists contain andalusite and garnet. The schists are isoclinally folded with a sub-horizontal fold-axis striking NNW-SSE. This folding has originated a new sub-vertical fracture-cleavage (fig. 2).

Thin sections clearly show that these fine-grained, schistose metasediments have undergone differentiation into mica-rich bands alternating with quartz-rich bands or two-mica schlieren with pegmatoid, metatexitic or granitoid, diatexitic bands. In the following, the mineralogical composition and some characteristics of the constituents will be discussed.

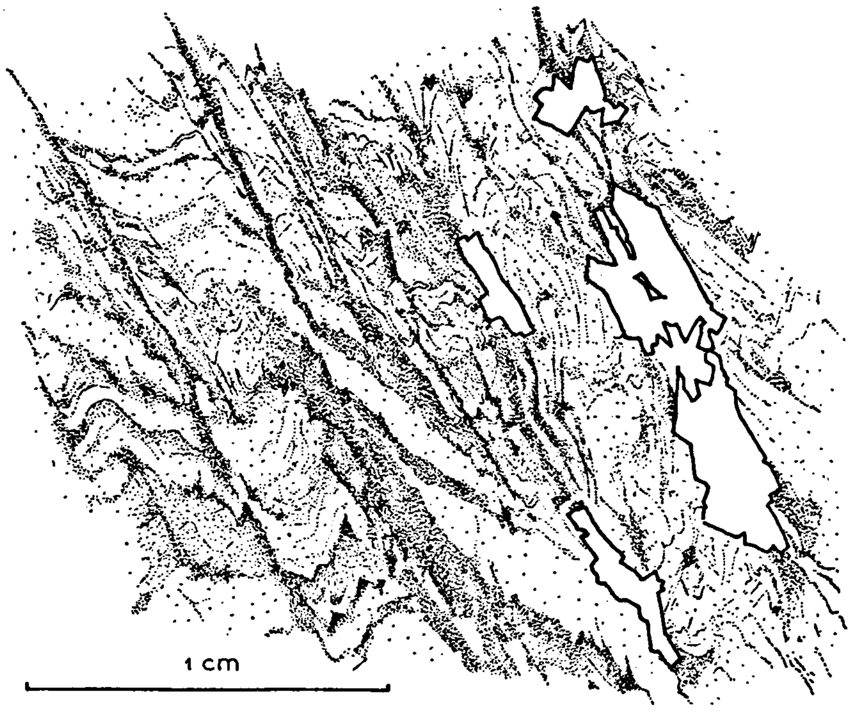

Fig. 2. Fracture-cleavage, superimposed on an older layering; the andalusites are post-kinematic.

Quartz. — One of the most important components is quartz, which occurs in two forms: elongate or equidimensional. The first is represented by crystals elongate parallel to the schistosity planes; they have a strong undulose extinction and a mutual amoeboid intergrowth originated by recrystallization of a granulated zone between two elongate grains. These crystals often have a preferred orientation of the optic axis parallel to the direction of tectonic transport (fabric *a*-axis). The second form, represented by equidimensional, equigranular, smaller crystals, with or without weak undulose extinction, shows the same preferred orientation. This form occurs in bands parallel to the schistosity. It is the so-called mosaic texture.

Plagioclase. — The plagioclase is an intermediate oligoclase, mostly homogeneous but sometimes normally zoned. Untwinned plagioclase crystals are more abundant than twinned; twinning is by pericline-law and sometimes by albite-law. The paragneisses of the Complejo Antiguo contain augen with frequent inclusions of biotite, quartz, and graphite. The biotite inclusions have a parallel orientation (S_i), forming an angle with the parallel-oriented external biotites (S_e). The augen were developed by metablastesis (Mehnert, 1957) after the formation of the S_i (plate III, fig. 2). The deformation which originated the S_e and by which the augen have been rotated slightly, gave these augen a cataclastic texture with recrystallization of quartz in the stress-shadows. The plagioclase is often strongly sericitized. One km NNW of Sierra de Outes there is a 5 cm thick layer containing a labradorite plagioclase, with quartz, a pale green hornblende, epidote, a strongly altered pyroxene, zircon, titanite, and magnetite. The schists contain plagioclase only as a minor accessory.

Potash-feldspar. — Cross-hatched microcline is always a minor accessory. A narrow band of a two-feldspar paragneiss found 2 km SE of Abelleira contains a very large amount of untwinned potash-feldspar.

Biotite. — A strong pleochroic biotite (Z, Y = chestnut- to red-brown, sometimes green; X = yellow) contains inclusions of zircon, allanite, and monazite giving pleochroic haloes in the biotite. It is often intergrown with muscovite, parallel to (001) and altered to chlorite in bands, also parallel to (001). The paragneisses of the Complejo Antiguo show two generations of biotite. The first generation is represented by very small flakes oriented parallelly in the plagioclase-augen. They form an angle with the biotites of the second generation which are much larger.

Muscovite. — The muscovite content in the paragneisses is much smaller than in the schists. There are two generations. The first generation is intergrown with the biotite. While this type is distributed homogeneously throughout the whole rock, the second type is concentrated only along some younger slip-planes lying parallel to the older schistosity. There are also some muscovites normal to the schistosity, the so-called cross-micas.

Andalusite. — There are two generations of andalusite. The first generation is pre-kinematic (plate III, fig. 3); micas have been bent round andalusite-augen. This type of andalusite is strongly altered to sericite. The second type is post-kinematic (fig. 2). Xenoblastic, inclusion-rich crystals are unstrained.

Accessories. — Zircon (well-rounded grains), apatite (large, xenomorphic grains), tourmaline (E = colourless to yellow, O = green core, yellow-brown rim), garnet (very few, small grains; $a_o = 11.560$; $n = 1.806$), magnetite (a major constituent of the quartzites; often as inclusions in chlorite and muscovite), titanite, sillimanite (near granite contacts; occurs sometimes as definite prisms, sometimes as fibrolite in biotite and muscovite), hornblende (pale green), pyroxene (only encoutered once), allanite (orange-coloured, metamict, pleochroic haloes in biotite), graphite.

Alteration products. — Chlorite (from biotite), rutile (always in chlorite), leucoxene (from titanite), sericite (from andalusite and plagioclase), sillimanite-fibrolite (from micas), epidote (from hornblende).

Amphibolites

The para- and orthogneisses of the Complejo Antiguo both show sills and lenses and sometimes discordant dikes of a strong linear amphibolite. It is a fine-grained green, gray or black rock with darker concentrations of hornblende. One example of a garnet-bearing amphibolite was found. It is impossible in this region to distinguish between ortho- and para-amphibolites, but both types are believed to be represented. The amphibolites within the orthogneiss and sometimes containing orthogneiss xenoliths (fig. 3), are of course ortho-amphibolites, but the lenses in the paragneiss are difficult to classify.

Mineralogically, there is little or no difference between the two types. They always contain 50—60 % hornblende, 15—30 % plagioclase, 1—17 % biotite, 4—7 % quartz, and some accessories and alteration products: chlorite, apatite, magnetite, titanite, rutile, graphite, allanite, garnet (a_o = 11.647; n = 1.763), zircon, epidote, and calcite.

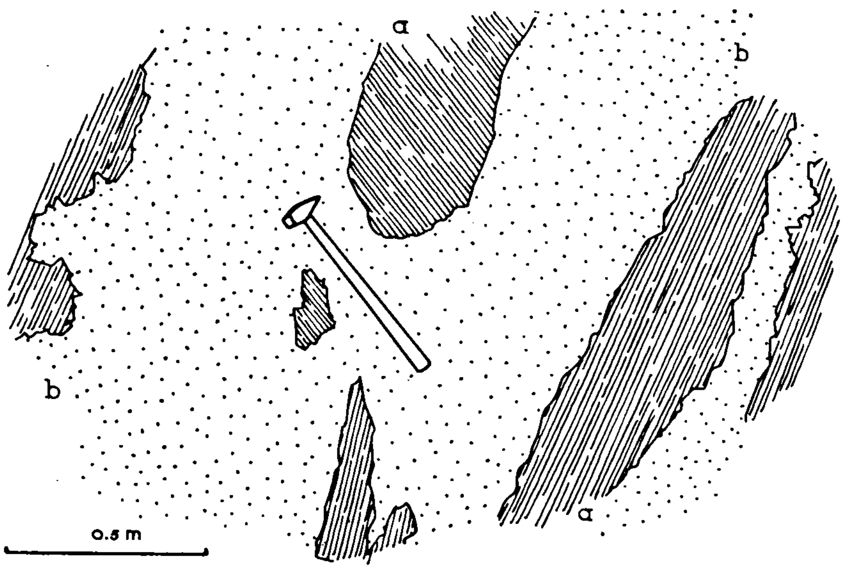

Fig. 3. Orthogneiss xenoliths (a) in a complex amphibolite sill (b).

Plagioclase. — The plagioclase is an acid andesine, always inversely zoned, sometimes metablastic with the same textures as the plagioclases in the paragneisses. The metablastic augen contain small, parallel-oriented hornblende crystals (S_i) forming an angle with the much larger parallel-oriented hornblendes (S_e) outside the augen. Graphite inclusions in strings parallel to the S_i are also found. This might be an indication of sedimentary origin.

Hornblende. — Both generations have the same characteristics: Z = blue-green, Y = olive-green, X = yellow-colourless; $Z \wedge c = 17°$; $2V_x = 76—81°$; [001] of the younger generation lies parallel to the fabric *b*-axis, or fold-axis (B); (010) has a preferred orientation in the S_e-plane.

PETROGRAPHY OF THE "PRE-CAMBRIAN" ORTHOGNEISSES

This region possesses two orthogneisses belonging to an older, probably Pre-Cambrian orogeny: the blastomylonitic orthogneiss and the coarse-grained augen-gneiss, which differ rather strongly. The ortho-amphibolites which are contained in the blastomylonitic orthogneiss have already been discussed in the preceding paragraph.

Blastomylonitic orthogneiss

The paragneisses of the Complejo Antiguo contain two large NNW-SSE-striking bands (500 to 700 m thick) and some small sills of this orthogneiss. The megacrystal biotite granite contains many xenoliths of this rock. The orthogneiss has a strongly linear texture. The lineation strikes NNW-SSE and is sub-horizontal. Sometimes it also has a foliation, though very weakly parallel to the schistosity in the paragneisses (plate III, fig. 4). It is a light-coloured, fine- to medium-grained rock, poor in micas, sometimes containing large feldspar-augen. Near the wrench-faults the lineation and the foliation are bent into N-S or NNE-SSW positions.

Thin sections provide strong evidence of marked mylonitization with subsequent recrystallization of quartz and feldspar. The feldspar blasts were later deformed to augen separated by finely crushed quartz bands; a second recrystallization of quartz took place in the stress-shadows and in cracks in the augen, normal to the foliation. The eastern band of orthogneiss is much less deformed and contains far more feldspar-augen with "flaser"-like biotite.

Quartz. — Four types of quartz are found. Firstly, the flat-lenticular, strongly undulose, crushed crystals parallel to the foliation. Between them there are zones and lenses of the second type: fine-grained, equidimensional, equigranular, non- or weakly undulose crystals representing the first recrystallization product (the so-called mosaic texture). The second deformation originated the very fine-grained crushed zones, always lying parallel to the first structures. The second recrystallization gave rise to amoeboid intergrowths of the oldest quartz grains where these grains lay among finely-crushed crystals. It also produced equigranular crystals in the stress-shadows of and in the tension-cracks in the feldspar-augen.

Potash-feldspar. The augen always consist of potash-feldspar, often with cross-hatching. They are always porphyroclasts lying in a fine-grained matrix. String- and patch-type perthite is common (Alling, 1938). There are also oligoclase inclusions, but they lack the preferred orientation of the albite inclusions in the perthites. This could point to a magmatic origin of this gneiss.

Plagioclase. — An acid oligoclase, seldom zoned and often sericitized in contrast to the albite of the perthite, is a minor constituent. Twinning occurs chiefly on the albite-law but also by pericline- and karlsbad-laws. Deformation-twins by albite-law are frequent (Vance, 1961). Myrmekitic plagioclase growing as warts into potash-feldspar is common.

Biotite. — "Flaser"-like biotite occurs in variable quantities; sometimes the rock seems to be a quartz-feldspar rock, sometimes it is very rich in biotite. The biotites lie parallel to the foliation or around the augen. A strong pleochroism ranges from chestnut, dark brown, or green for Y, Z to yellow or colourless for X. Zircon and allanite inclusions, give pleochroic haloes in the biotite.

Accessories. — Zircon (idiomorphic or crushed; zoned with turbid cores), allanite (orange or yellow, isotropic), garnet, titanite, fluorite (irregular fillings between other crystals).

Alteration products. — Sericite (in plagioclase), chlorite (from biotite), epidote (as a rim around allanite), rutile (in chlorite).

Pegmatite

The paragneisses sometimes contain a strongly mylonitized pegmatite containing quartz, microcline, a very large amount of albite, garnet (a_o = 11.549—11.557; n = 1.805), a little muscovite, very little biotite, apatite, zircon, magnetite, and rarely beryl.

Coarse-grained augen-gneiss

Coarse-grained augen-gneiss is the most abundant rock type between Freijo and Esteiro. The strike of the foliation is between 320° and 350°, the dip being steep to the SW. The gneiss contains large feldspar-augen with the longest axis (up to 5 cm) almost horizontal in the foliation-plane. "Flaser"-like biotite and muscovite flakes are bent around the augen. The ground-mass is fine-grained and contains much quartz. The foliation-plane symmetrically dissects two sets of slip-planes forming an angle of 50° to 60°, as a result of which the augen-gneiss has a strongly phyllonitic appearance (plate IV, fig. 1). The augen-gneiss has in some places undergone migmatization.

In thin sections the augen-gneiss differs from the orthogneiss of the Complejo Antiguo in several features: firstly, the texture is phyllonitic rather than mylonitic; secondly, by the large content of muscovite and the anorthite content of the plagioclase. It contains the same types of quartz. The larger augen are always of microcline which is perthitic (string- and vein-type). They contain randomly-oriented plagioclase inclusions. Around the microcline augen there is often an albite mantle, the result of later albitization. The plagioclase augen are always smaller and consist of albite, sometimes slightly zoned. The muscovite exists in two generations, one intergrown with biotite, parallel to the foliation or the two slip-planes, and a younger type in the form of cross-micas. The younger muscovites sometimes contain needles of sillimanite. Apatite appears as larger xenomorphic crystals than in the orthogneiss. Zircon is idiomorphic or a little rounded. Also present are chlorite, rutile, allanite, and tourmaline (green cores and yellow-brown rims).

PETROGRAPHY OF THE "EARLY-HERCYNIAN"MEGACRYSTAL BIOTITE GRANITE

Xenoliths

The megacrystal biotite granite, the so-called trondhjemite of Parga Pondal (1956) contains many xenoliths. Firstly, there are blastomylonitic orthogneiss xenoliths, from the Complejo Antiguo (fig. 4); secondly, there are paragneiss (fig. 5) and amphibolite xenoliths. The xenoliths mostly lie parallel to the foliation of the megacrystal granite but are sometimes discordant (fig. 5). Balls and lenses of a darkish, slightly foliated, fine-grained diorite also occur (plate IV, fig. 2).

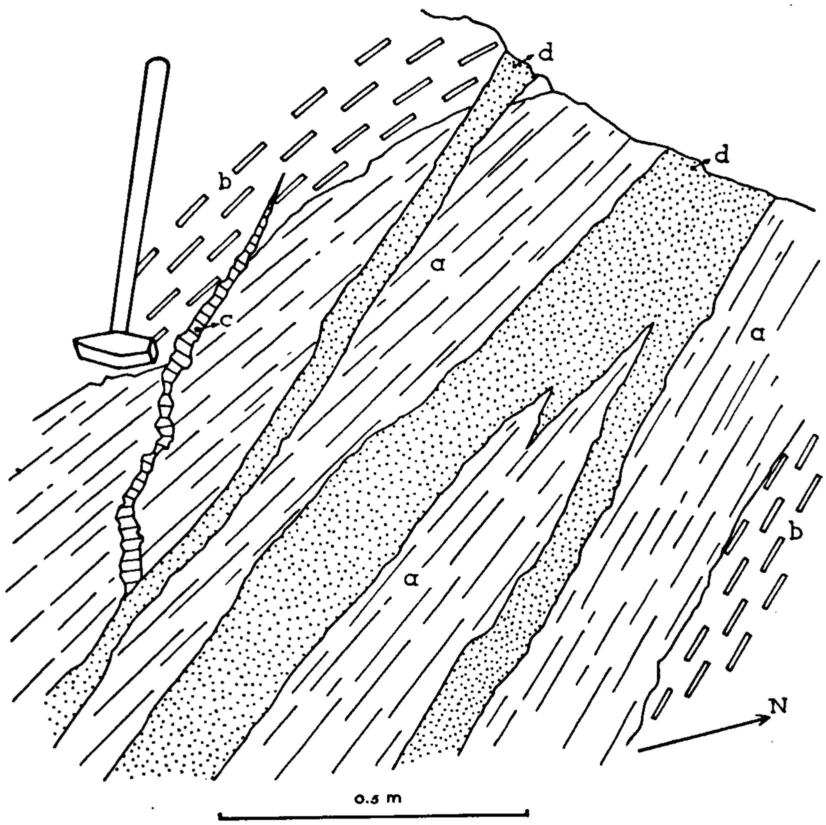

Fig. 4. Elongate orthogneiss xenoliths (a) have an orientation parallel to the foliation of the megacrystal biotite granite (b). A younger aplite vein (c) is cut by the Barbanza granite (d).

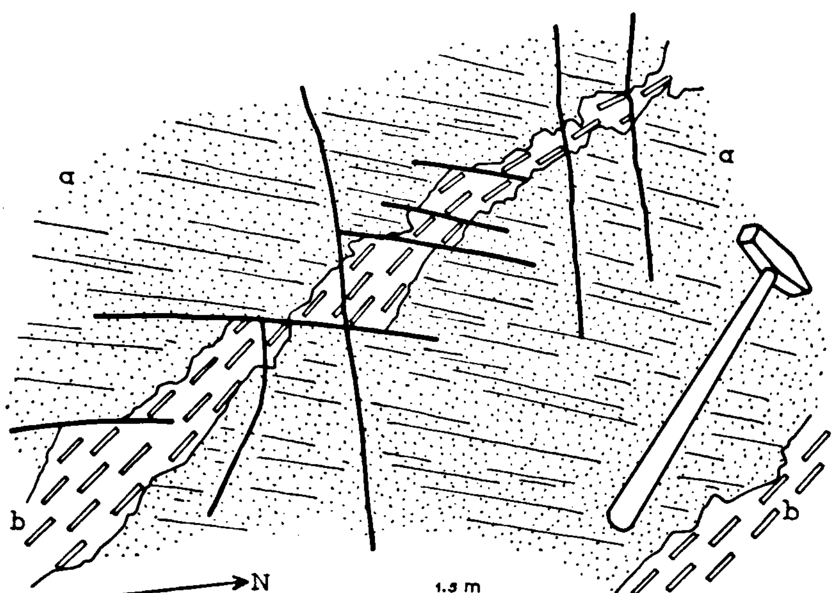

Fig. 5. The foliation of the paragneiss (a) is not oriented parallel to the foliation of the megacrystal biotite granite (b). Two sets of oblique shear-joints of the {0kl} type are present; one set has functioned as true tear-faults.

In thin sections the mineral content of these diorites makes it possible to distinguish three groups: 1. quartzdiorite, 2. biotite granodiorite, and 3. hornblende diorite. The quantitative content determined by point-counter analysis is shown in Table I. In the sample of granodiorite, 1000 points were counted; in the other two only 500.

TABLE I

	AL-43 Quartzdiorite	AL-293 Biotite granodiorite	AL-526 Hornblende diorite
Quartz	11.8 %	21.7 %	0.2 %
Plagioclase	44.4	43.0	30.8
Microcline	+	12.3	+
Biotite	39.6	21.6	5.4
Chlorite	+	0.4	+
Hornblende	—	—	59.8
Apatite	0.8	0.3	—
Zircon	+	0.1	—
Titanite	2.8	0.6	0.2
Magnetite	0.2	+	3.6
Allanite	0.4	—	—
	100.0	100.0	100.0

+ = present, but not counted.

Quartz. — The quartz grains are mostly equidimensional, slightly undulose, but sometimes — along sheared zones or lenses — they are elongate parallel to the foliation. Amoeboid intergrowth is frequent in such cases.

Plagioclase. — The plagioclase is normally zoned from a basic to an acid andesine or from an acid andesine to a basic oligoclase. Inverse zoning is rare. They are often developed as augen, in which case there are many deformation twins. The augen are originated by metablastesis followed by cataclasis (Mehnert, 1957). They contain many inclusions of quartz, biotite, and apatite (plate IV, fig. 3). The plagioclase is often sericitized, the core more so than the rim. The potash-feldspar in the biotite granodiorite contains many randomly-oriented plagioclase inclusions which give them a magmatic appearance.

Potash-feldspar. — Cross-hatched potash-feldspar is a major constituent in the biotite granodiorite. It is perthitic and often has a rim of myrmekitic plagioclase. The plagioclase in the myrmekite and perthite is an albite which is never sericitized, in contrast to the more basic plagioclase inclusions in the potash-feldspar. In the two other types of diorites, potash-feldspar is a minor accessory. Megacrysts are sometimes found astride the contact of the megacrystal biotite granite and the xenolith (plate IV, fig. 2).

Biotite. — Biotite is always a major constituent, oriented parallel to the foliation. Strong pleochroism goes from red-brown and green (Y,Z) to yellow (X). Pleochroic haloes are frequent around zircon and allanite inclusions.

Hornblende. — Hornblende is commonly concentrated in small nodules. It has a pleochroism from blue-green (Z) to olive-green (Y) to yellow-colourless (X). It has pleochroic haloes around zircon and allanite inclusions. Often the [001]-axis of hornblende has a preferred orientation in the tectonic B-direction.

Accessories. — titanite, zircon (well-rounded), apatite (in the granodiorite in large quantities, as large xenomorphic crystals), allanite (orange or yellow; (100)-twins common), magnetite, tourmaline (brown-green).

Alteration products. — Sericite (in plagioclase), chlorite (fine bands in biotite), epidote (rims around allanite).

The origin of these diorites is problematic. It seems likely that the hornblende diorites are anatectic amphibolites of the Complejo Antiguo. Many orthogneiss xenoliths belonging to the same complex have been found here. Typical paragneiss xenoliths are very scarce. It is possible that the quartzdiorites are anatectic products of these paragneisses. They often show the same characteristics, as metablasts with many inclusions, and approximately the same composition. The higher anorthite content in the plagioclases of the xenoliths may have resulted from partial fusion or migration of the albite content into the megacrystal biotite granite. The biotite granodiorite has a magmatic appearance and could be an older differentiation product of the megacrystal biotite granite.

Megacrystal biotite granite

The megacrystal biotite granite is a foliated rock containing many idiomorphic feldspar crystals measuring up to 5 cm in length, with a fine- to medium-grained, very dark, biotite-rich ground-mass. The megacrysts are tablet shaped and almost always lie in a NNW-SSE direction parallel to the foliation which is marked by parallel orientation of the biotites (plate IV, fig. 2). The dip of the foliation and of the feldspar tablets is variable, but it is mostly rather steep. Some zones are strongly deformed along N-S-striking shear-planes (plate IV, fig. 4), giving rise to a phyllonitic appearance. This is often the case near the contact of the granite with the Complejo Antiguo.

In thin sections the megacrystal biotite granite always shows foliation, the feldspar megacrysts being preferably oriented with (010) parallel to the foliation. The megacrysts are mostly of potash-feldspar, but there are also plagioclase megacrysts although these are always smaller.

Quartz. — Once again there are three types of quartz: large, elongate, strongly undulose crystals; finer equigranular, equidimensional ones without undulose extinction, i.e. mosaic texture, and along slip-planes, zones of very finely-crushed crystals of a later deformation.

Potash-feldspar. — The megacrysts or incipient augen are mostly cross-hatched, sometimes with karlsbad-twins. They contain many inclusions: biotite (sometimes oriented parallel to morphological planes), chlorite, plagioclase (randomly oriented, idiomorphic laths, strongly sericitized). The microcline is often perthitic, with string-, vein- and patch-type perthites. Wart-like myrmekitic plagioclase seems to grow from the border into the microcline. Tension-cracks, normal to the foliation, occur in the augen and are filled with quartz and biotite. Around diorite xenoliths the granite contains no potash-feldspar; this is perhaps due to potash-migration into the xenolith (Turner and Verhoogen, 1960, p. 157).

Plagioclase. — The plagioclase megacrysts are always smaller than the potash-feldspar megacrysts. They show normal or oscillatory zoning. Twinning occurs principally by the albite-law, but also by the pericline- and karlsbad-laws. Deformation twins are frequent. The plagioclases within or adjoining potash-feldspar have an albite rim. The anorthite content lies between 38 and 17 %, excluding the secondary albite rims, the myrmekite, and the perthite.

Biotite. — Biotite is always a major constituent. Its pleochroism goes from red-brown or grass-green (Y,Z) to yellow (X). Small biotites are sometimes included in potash-feldspar megacrysts lying parallel to previous morphological planes of their host crystal. Biotite contains inclusions of titanite, zircon, and allanite (the last two causing pleochroic haloes).

Accessories. — Zircon (small, idiomorphic, or crushed grains), apatite (large, xenomorphic crystals), tourmaline (brown-green), titanite, allanite, and magnetite (sometimes as a rim around biotite).

Alteration products. — Chlorite (from biotite), epidote (as a rim around allanite), and sericite (in plagioclase).

Coarse-grained two-mica granite

This granite, occurring infrequently in such very small dikes and bodies that it is not indicated on the map, is a very coarse-grained and slightly foliated rock. The feldspars are not idiomorphic. The granite is poor in micas but contains biotite as well as muscovite. The plagioclase is a more acid one, normally zoned from acid oligoclase to albite. This rock intruded into the megacrystal biotite granite and is believed to be a later differentiation product of the same source as the megacrystal biotite granite.

Muscovite granite

In the megacrystal biotite granite there are many narrow dikes, varying from several centimetres to a metre in width, often lying parallel to the NNW-SSE-striking foliation, and sometimes discordant. These dikes contain a very gneissic muscovite granite. Some dikes of this rock have been found in the schist band located NW of Freijo. Two larger bodies occur, one on the Tremuzo and the other 1½ km SW of Rates. The foliation of the megacrystal biotite granite is not bent around these bodies: both the foliation and the lineation of the muscovite granite are always parallel to those in the megacrystal biotite granite. The muscovite granite is a fine- to medium-grained rock, very gneissic, sometimes with biotite patches. This rock is rich in tourmaline. Here, too, there is a secondary N-S-striking vertical cleavage due to a second deformation.

Associated with this rock is a gneissic aplite, containing the same biotite patches, and garnet. Furthermore, there is a very coarse-grained pegmatite.

All these rock types occur in or near the megacrystal biotite granite; it is therefore believed that these rocks belong to the same granitic cycle as later differentiation products.

In thin section the strong deformation is very clear. Between areas of fine-grained ground-mass there are medium-grained cataclastic feldspar crystals. The texture of the quartz, potash-feldspar (except the idiomorphism), and plagioclase is the same as for the megacrystal biotite granite. The plagioclase is less calcic: an albite, and never zoned.

Muscovite. — Muscovite is an important constituent. It has been bent around feldspar cataclasts. There are also secondary muscovites, parallel to the foliation or normal to it (cross-micas). The second generation contains small inclusions of an opaque ore-mineral and sometimes sillimanite needles.

Accessories. — Biotite (if present, always in patches), zircon (idiomorphic), apatite (in larger quantities; always xenomorphic), an opaque ore-mineral, tourmaline (olive-green), sillimanite (in muscovite) and childrenite-eosphorite (zoned).

The gneissic aplite also shows a reddish garnet ($a_o = 11.546$; $n = 1.805$) containing quartz inclusions and altered along cracks into a green biotite.

PETROGRAPHY OF THE "HERCYNIAN" PALINGENIC GRANITES

Metatexitic gneisses, diatexitic gneisses, diatexites

As has already been mentioned, the metasediments have undergone migmatization. The paragneisses of the Complejo Antiguo show no migmatization or only an incipient stage. Segregations of quartz, sometimes with andalusite, are the only indications of metamorphic differentiation. In the schist band near Freijo and the schist complex around Corga the rocks have been transformed to metatexitic

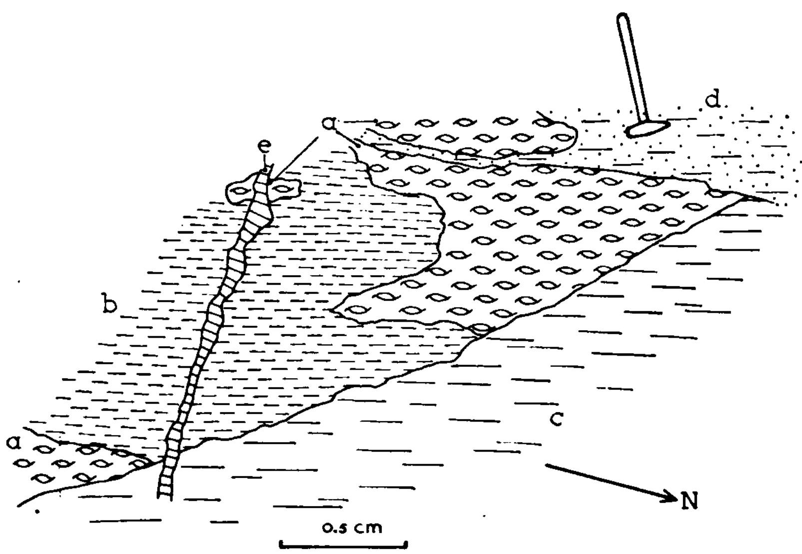

Fig. 6. The coarse-grained augen-gneiss (a) was intruded first by the diatexitic granite (b), then by an aplite with biotite patches (c), and thereafter by the biotite-rich type of the Barbanza granites (d). The pegmatite (e) is probably younger.

gneisses: layers and bands of biotite, muscovite, and quartz, with lenses or veins of pegmatitic material (plate III, fig. 1). Along the contact of these two bands there are often tourmaline concentrations. Lenses and veins of granitic material also occur, causing the diatexitic gneisses. The highest stage of migmatization is represented in the eastern sector by bodies of diatexites: most of the rock went through a molten stage and crystallized into a fine-grained two-mica granite, foliated by later phases of deformation, often still containing remnants of the older rock in the form of patches and schlieren of biotite and muscovite. In some places this rock began to move and intruded into the host rock in the form of veins and dikes, as in the coarse-grained augen-gneiss (fig. 6) which was also migmatized locally, giving rise to a weakly-foliated, very coarse-grained, rather patchy granite. A xenolith of diatexite has been found in the younger palingenic granites of the Barbanza-type.

Aplite

Perhaps connected with the diatexites is a gneissic aplite (fig. 6) which is intruded into the diatexite and has in turn been intruded by the younger Barbanza granites. The aplite is a white fine-grained rock with some biotite patches.

Palingenic granites of the Barbanza-type

All the afore-mentioned rocks are intruded by two-mica granites of the Barbanza-type. Veins and dikes of these granites also intruded the megacrystal biotite granite, the muscovite granite, and the schists. They are for the most part medium-grained with a gneissic texture, although fine- and coarse-grained types are also present. Independent of grain-size, they can always be divided into two types: an older light-coloured, muscovite-rich type and a younger, darker, biotite-rich type (plate V, fig. 1). Both types contain two-mica lenses lying parallel to the foliation. Sometimes the granites contain potash-feldspar megacrysts and pegmatitic patches. There are also many pegmatite veins both parallel and normal to the foliation. In certain zones these granites, with their NNW-SSE-striking foliation, were sheared during later phases of deformation along N-S-striking slip-planes. The Barbanza granites are a very inhomogeneous group, not only with respect to the grain-size but also because of their variable composition and colour, and the intensity of the later deformations. The grain-size is probably inversely proportional to the degree of deformation. This is plainly visible in the field from geomorphological features: as soon as traces of deformation vanish, the granites weather into rounded tors (for instance on the N-S-striking ridge W of Abelleira). Regardless of the many local variations these two types are always represented, so that it is likely that they all belong to the Barbanza group of granites. The two types are so intermingled that it is impossible to differentiate them on a 1 : 25000 map.

Palingenic granites of the Muros-type

About 3 km SW of Abelleira the medium- to coarse-grained Barbanza granites were intruded by a medium-grained, gneissic, two-mica granite of Muros-type. This granite has very large biotite flakes with ragged outlines. Near the contact it contains some xenoliths of the Barbanza granites. This medium-grained Muros granite forms an arcuate border zone, about 500 m in width, around the intruding fine-grained, gneissic two-mica granite of the Muros-type. Around the village of Muros this granite forms a very homogeneous rock with a strongly developed foliation, striking NW-SE.

It contains large flakes of muscovite. To the NE of Sierra de Outes a large body and some dikes of the same granite are found. On Monte Louro, SW of Muros, the Barbanza granite appears again, sometimes without any foliation but otherwise with a NNW-SSE-striking one. The peninsula of Monte Louro probably developed because of the presence between it and the mainland of some easily-eroded schistose xenoliths. Between Monte Louro and Muros some xenoliths of medium-grained Muros granite occur.

The fine-grained Muros granite contains small, rounded inclusions, several decimetres in diameter, of a still finer and darker two-mica granite which has also been found in the granite body, NE of Sierra de Outes.

Mineralogy of the palingenic granites

All these rocks show the same minerals and textures; they differ only in grain-size and quantitative composition. The compositions are given in Table II. In each thin section 1500 points were counted. The inhomogeneity of the Barbanza granites and the homogeneity of the Muros granites, especially of the fine-grained type, is rather obvious.

Quartz. — The quartz has been mainly developed as elongate, strongly undulose crystals lying parallel to the foliation. Along shear-zones the quartz has been granulated. Recrystallization gave rise in some cases to amoeboid intergrowth of larger undulose quartz grains, in others to a mosaic texture.

Potash-feldspar. — Mostly cross-hatched, the potash-feldspar contains numerous randomly-oriented plagioclase inclusions bearing evidence that its crystallization took place later than that of the plagioclase. String-type perthite is common in the Barbanza granites but is never found in the younger Muros granites (plate V, fig. 2). This type of perthite often disappears towards the boundary of the feldspar. Alling (1938) thought it to be a result of exsolution. Vein- and patch-type perthite occur in all these granites, in the Barbanza as well as in the Muros granites (plate V, fig. 3); these types are represented by irregular veins, roughly parallel to (001) of the potash-feldspar, and patches of an albitic plagioclase with twinning by the albite-law, parallel to (010) of the host. These types are always accompanied by an albitic rim around the potash-feldspar. This seems to be sufficient evidence to support a later sodium replacement yielding albitization. In exceptional cases a later potash-feldspar growth occurred at the cost of plagioclase. Potash-feldspar megacrysts are very rare.

Plagioclase. — The plagioclase mostly crystallized before the potash-feldspar and is twinned principally by the albite-law and sometimes by the pericline- and karlsbad-laws. Secondary deformation-twins are common. Myrmekite occurs in all but the Muros granites. There is no significant difference between the plagioclases of the two Barbanza-type granites; they are weakly- and normally-zoned plagioclases ranging from An 12 to almost pure albite. The same applies to the diatexites. The more basic plagioclases are often sericitized. In contradistinction, the Muros granites always contain an albitic plagioclase.

Biotite. — Biotite has a strong pleochroism from red-brown or green (Z, Y) to yellow (X). In the medium-grained Muros granite the biotite flakes are relatively large with ragged outlines. Zircon and allanite inclusions cause pleochroic haloes. The biotites also contain inclusions of rutile and titanite. Alteration to chlorite is common.

TABLE II

Mineralogical compositions of: a diatexite (a), four samples of the muscovite-rich type of the Barbanza granite (b), four of the biotite-rich type (c), two samples of the medium-grained Muros granite (d), and two of the fine-grained Muros granite (e).

	a	b				c				d		e	
	AL-588	AL-269	AL-442	AL-600[2]	AL-601	AL-148	AL-270	AL-275	AL-600[1]	AL-436	AL-639	AL-425	AL-438
Quartz	26.6	30.6	31.0	53.9	35.9	39.8	37.4	40.7	33.0	28.8	31.6	37.2	36.2
Potash-feldspar	34.7	17.2	23.6	6.4	26.8	18.2	14.6	25.8	17.1	35.0	29.4	28.2	28.2
Plagioclase	22.5	35.0	29.4	22.0	17.0	21.4	17.0	15.2	22.8	22.6	15.2	14.4	15.0
Muscovite	10.3	14.4	14.6	15.5	16.6	7.4	15.0	11.0	14.6	11.6	16.2	13.0	14.8
Biotite	5.7	2.4	1.2	1.9	3.5	12.4	14.7	6.5	10.9	2.0	7.4	6.4	4.4
Chlorite	0.1	—	—	—	—	0.2	—	+	0.2	—	—	+	0.2
Zircon	+	+	+	+	+	+	+	+	0.1	+	0.2	0.2	0.4
Apatite	0.1	0.4	0.2	0.1	0.2	0.2	1.0	0.4	1.0	+	+	0.6	0.8
Sillimanite	—	—	—	0.2	+	—	—	—	+	—	+	—	+
Ore-mineral	+	+	—	+	—	0.4	+	0.4	0.2	—	+	—	+
Titanite	+	—	+	+	—	—	0.2	+	0.1	—	+	—	+
Tourmaline	—	+	—	+	—	—	0.1	—	—	—	—	+	+
Rutile	+	—	—	—	+	+	—	—	+	—	—	+	—
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

+ = present, but not counted.

Muscovite. — There are two generations of muscovite. The smaller ones are often intergrown with biotite. The larger muscovites have ragged outlines and often contain very small ore inclusions and sillimanite needles. This last type seems to be the younger generation, showing less preferred orientation than the smaller ones. Both types are bent and have knick-zones.

Accessories. — Zircon (always well-rounded), apatite (relatively large, xenomorphic crystals), titanite and rutile (as inclusions in biotite and chlorite), tourmaline (blue- or olive-green), sillimanite (in muscovite), allanite, and an opaque ore-mineral.

Alteration products. — Sericite (from plagioclases), chlorite (from biotite), leucoxene (from titanite).

The gneissic aplite which intruded the diatexites contains quartz, albite, microcline, and muscovite as the principal constituents. Accessories are zircon (well-rounded), apatite, tourmaline, garnet ($a_0 = 11.548$; $n = 1.815$; with a sieve structure caused by numerous quartz inclusions; altered along cracks into a green biotite with rutile), β-zoisite, and clinozoisite.

PETROGRAPHY OF THE POST-TECTONIC IGNEOUS ROCKS

Biotite granite of Pando

East of Pando and north of Esteiro a nearly oval intrusive body is found in a discordant position with respect to the country rocks. It consists of a medium- to coarse-grained biotite granite totally lacking any foliation. It may be referred to the so-called Traba-type granites of Parga Pondal (1956). The Pando granite has a finer-grained chilled margin, but there is no contact-aureole in the adjacent gneissic Barbanza granites. The schistosity and foliation in the country rock do not deviate from their normal NNW-SSE strike. The intrusion therefore cannot have been due to "forcible injection". The properties of the body agree with those of a "stock" as defined by Billings (1945). The mode of emplacement is not "piecemeal stoping"; because of the lack of xenoliths, but it could have been due to "ring-fracture stoping". Indeed, fractures occur that are vertical or dip steeply outwards, sometimes even down to 45°, e.g. near Esteiro. The granite has its own joint-pattern which is totally different from those in the gneissic granites. Quartz veins sometimes occur along the joints. Some large N-S-striking master-joints, cutting through the whole body and causing a parallel drainage pattern, seem to have been inherited from the older systems that once must have formed the roof of the Pando granite as well.

Two samples of the biotite granite have been point-counted (1500 points per sample). The results are given in Table III.

Quartz. — Quartz is always either very weakly undulose or not at all; the grains are equidimensional and xenomorphic. They probably crystallized in remaining pores between the other minerals.

Potash-feldspar. — Always cross-hatched, the potash-feldspar contains much exsolution perthite and very much replacement perthite. It also contains many randomly-oriented plagioclase inclusions, strongly sericitized.

TABLE III

	AL-186	AL-220
Quartz	22.6 %	18.1 %
Potash-feldspar	35.8	35.6
Plagioclase	37.0	38.0
Biotite	3.8	6.5
Sericite	0.4	0.8
Chlorite	0.2	0.6
Apatite	0.1	0.2
Zircon	+	0.1
Allanite	0.1	+
Ore mineral	+	0.1
	100.0	100.0

+ = present, but not counted.

Plagioclase. — The plagioclase is always normally zoned, with a oligoclase core (up to An 16) and an albitic rim. The cores are more strongly sericitized than the rims. Twinning is principally by the albite-law but also by the karlsbad- and pericline-laws. Deformation-twins are very scarce. Myrmekite occurs very frequently (plate V, fig. 4). Later sodium replacement or albitization is very common. Some decalcification of the plagioclase took place, causing very irregular zoning.

Biotite. — Biotite has a pleochroism from dark-brown or green (Y, Z) to yellow (X). It contains allanite and zircon inclusions which cause pleochroic haloes. Alteration to chlorite is not common.

Accessories. — Zircon (idiomorphic or crushed; zoned), apatite (small amounts), allanite (zoned), magnetite, and fluorite (small amounts).

Alteration products. — Sericite (in basic plagioclase) and chlorite (from biotite).

Granite porphyry

In the vicinity of the Pando granite, some dikes of granite porphyry are found. They are 5 to 30 m thick. The porphyry contains medium-grained phenocrysts of quartz, feldspar, and biotite in a very fine-grained ground-mass. There is no difference between the margins and the inner parts of a dike. The porphyry has its own joint-pattern, rather different from that of the adjacent older rocks. The phenocrysts are mostly corroded.

Quartz. — Quartz phenocrysts are idiomorphic or rounded, corroded, and sometimes crushed. In the ground-mass the quartz is xenomorphic.

Potash-feldspar. — Cross-hatching is common. Most of the potash-feldspar phenocrysts are idiomorphic. They have an outer rim with many quartz inclusions, perhaps caused by later growth when the magma was in situ. They have also plagioclase inclusions. Vein-type perthite is common.

Plagioclase. — The plagioclase phenocrysts are also idiomorphic. They consists of almost pure albite. Strong sericitization took place.

Biotite. — Strongly-corroded flakes of dark-brown or green pleochroic biotite contain inclusions of an opaque ore-mineral.

Zircon. — Zircon occurs as an accessory. It is either idiomorphic or crushed.

Alteration products. — Chlorite (from biotite), epidote (in chlorite), and sericite (in plagioclase).

Lamprophyre

In some places lamprophyre dikes occur; three dikes occur 3 km NNE of Pando, one occurs 2 km WSW and another 2 km NE of Sierra de Outes; some others occur 1½ km and 4 km NNW of Corga. These are narrow dikes, not exceeding 1 m in width. The rock is dark coloured and fine-grained. It contains phenocrysts of hornblende only (up to 2 mm), some quartz patches or lenses (1 mm), and some large epidote crystals as alteration products in biotite, chlorite and hornblende. The ground-mass contains smaller hornblendes (¼ mm), plagioclase laths (andesine or basic oligoclase), an opaque ore-mineral, titanite, small amounts of quartz, biotite, and secondary calcite (in plagioclase).

Hornblende. — Hornblende occurs in two generations. Both are idiomorphic. They are sometimes zoned. Pleochroism varies from green or dark-brown (Z), via olive-brown (Y), to yellow (X); $2Vx = 78°$; $Z \wedge c = 19°$. Twinning by (100) is common. Hornblende has been altered to chlorite and epidote.

STRUCTURAL GEOLOGY

Phases of deformation

Relics of the oldest tectonic phase, probably of Pre-Cambrian age, have been found in the Complejo Antiguo and only in the plagioclase metablasts of the paragneisses, represented by the parallel orientation of biotites and hornblendes ($S_i = S_o$). It is very likely that the schistosity-planes in the schist band and in the xenoliths of the Barbanza granites were at least partially formed during the same Pre-Cambrian orogenic phase.

The first "Hercynian" phase of deformation (D_1) folded these rocks isoclinally with a nearly horizontal fold-axis, forming a new axial-plane cleavage ($S_e = S_1$). This is clearly visible near Abelleira (fig. 2). The tectonization was stronger than in any subsequent phase. The Complejo Antiguo derived from this tectonic phase its present appearance: the mylonitization of the orthogneisses, the foliation of the paragneisses, and the phyllonitization of the coarse-grained augen-gneiss. The schistosity almost always has a NNW-SSE-strike and a very steep dip. Only in the vicinity of the younger wrench-faults has the strike been rotated to a N-S, or even a NNE-SSW position.

The second "Hercynian" phase of deformation (D_2) took place simultaneously with or shortly after the intrusion of the palingenic granites and gave the rocks the same NNW-SSE-strike as the first phase. Near Muros there is a local deviation from this strike to a NW-SE position. The effect of this phase was not as strong as that of the first. While the first phase caused a penetrative deformation of the whole rock, the second deformation took place along local zones; it was a non-affine deformation. This condition is clearly visible in thin sections of rocks of the Complejo Antiguo: in the paragneisses the micas oriented parallelly in the first phase are distributed homogeneously throughout the rock but younger and larger muscovites have grown along certain shear-zones (S_2), mostly parallel to the older S_1-planes. In the blastomylonitic orthogneisses these shear-zones are represented by zones of very finely crushed quartz crystals, also often parallel to S_1. The megacrystal biotite granite and its suite of associated rocks became foliated during this phase of deformation.

The third "Hercynian" phase of deformation (D_3), even weaker than the second, took place immediately after the latter. This was a flattening deformation on a vertical B-axis, which operated on N-S-striking vertical slip-planes (S_3) probably caused by the same major stress direction as the other two "Hercynian" phases. The third phase is responsible for the phyllonitic structure of many of the gneissic granites (plate IV, fig. 4). This deformation took place only in rather narrowly defined zones: a very strongly phyllonitized zone is found near Abelleira.

The dextral N-S-striking wrench-faults were apparently a further product of the same stress-field. In all likelihood there are more wrench-faults in the area than are indicated on the map. The form of the Ría de Noya y Muros could be explained by faults; there is also a little shifting of the rock boundaries N and S of the Ría. Near these faults the S_1- and S_2-foliations have been dragged into N-S positions. This is clearly visible on the map and on the stereographic diagrams of foliations shown along the upper and lower margins of the map. For example, diagrams AL-584 in the coarse-grained augen-gneiss, AL-592 in the megacrystal biotite granite, AL-15 in the blastomylonitic orthogneisses, and AL-493 in the diatexite exhibit this feature.

Near a supposed wrench-fault in the Ría, SW of Corga, there are many small knick-zones (fig. 1) in the paragneiss, striking NE-SW with a nearly vertical dip. These knick-zones are sinistral, and could be complementary to the dextral wrench-faults.

Conceivably, before the appearance of the wrench-faults there was a phase of relaxation which caused a "graben" of the Complejo Antiguo. The rocks of this group are not or only very slightly migmatized, only metablasts and quartz segregations occurring. Consequently, they could be rocks derived from a higher level of the orogene. The graben structure must be older than the wrench-faults because the boundaries of the Complejo Antiguo are displaced by them.

Joint-systems

Four important types of joints are found:

1. *ac*-joints or tension-joints (de Sitter, 1956, p. 131). These joints are normal to the foliation and lineation. They have been found everywhere (see diagrams on the map), except in the post-tectonic igneous rocks. The diagrams representing the joints in the Complejo Antiguo clearly show the rotating effect of the wrench-faults. The occasionally double maxima are due to the fact that measurements were taken in too large an area where the effect of the wrench-faults is already considerable. These joints sometimes functioned as faults as in AL-493 where some fault striations have been measured.

2. Oblique-shear joints (de Sitter, 1956), of the {0kl} type, parallel to the fabric *a*-axis and forming an angle with *b* and *c*. This system has two sets of joints, the foliation being the acute bissectrix of the two. These joints often functioned as small wrench-faults (fig. 5). This system is very well developed in all granites but only very weakly in the rocks of the Complejo Antiguo.
3. *ab*-joints or release tension-joints (de Sitter, 1956). In some of the diagrams these joints, normal to the direction of the major stress, gave small maxima. They may, however, be deviations of type 4.
4. Thrust-shear-joints (de Sitter, 1956) of {h0l} type, parallel to fold-axis *b*, forming an angle with *a* and *c*. These are not very common but where they are present they are very large, having functioned as fault-planes.

In the granites of the peninsula of Noya, von Raumer (1963) has found many nearly horizontal joints. These joints are very rare in this region; in newly-developed quarries they are absent, and only a few are found in granite bodies long exposed on mountain tops. They are probably caused by exfoliation.

The joint-systems of the Pando biotite granite have nothing to do with all the systems just described. Some conspicuous N-S-striking master-joints may have been inherited from the host rock or be due to subsequent normal faulting.

PETROFABRIC ANALYSIS

Introduction

Some selected rock samples were subjected to petrofabric analysis of the {001} cleavage of the micas and the optic axis of quartz. To evaluate the "blind spot" for micas, two analyses were made of thin sections normal to each other. Two hundred {001} of micas and 200 quartz axes were measured in the sections normal to the lineation (*b* = B), and 100 {001} of micas in the sections parallel to *b* and *c*, normal to *a*.

Measurements were carried out with the universal stage, and plotted on an equal area projection using the lower hemisphere. Contours were drawn by the free-counter method described by Turner and Weiss (1963, p. 62).

Because the lineations are almost horizontal, the *ac*-sections normal to *b* are nearly vertical but the *bc*-sections normal to *a* may have a considerable dip which is dependent on the dip of the schistosity-planes.

The thin sections normal to *b* were cut from the SSE-side of rock samples and those normal to *a* from the upper side.

Description of the fabrics

Paragneiss. — (plate I, fig. 1). Poles to {001} of mica lie in a complete girdle around *b* with a large 15 % maximum near *c*. There are some smaller maxima, corresponding to the planes S_2, S_3, S_4, and S_5, making angles of 40°, 44°, 67°, and 65° respectively with S_1. The newly-grown muscovites have the same orientation pattern as the biotites, and are therefore combined in a collective diagram. The section normal to *a* shows a strong maximum near *c*. The very weak maximum corresponding to S_6 may be related to the third or wrench-fault phase of deformation. The still weaker and perhaps insignificant maximum corresponding to S_7 could be the complementary set. Both form an angle of 30° with S_1.

Quartz axes also show a girdle orientation around *b*, but this is incomplete, having minima near *a* and *c* and some weak maxima near the intersections of S_2 and S_3 with the girdle. There are also suggestions of the beginning of concentrations of quartz axes in the S_6- and S_7-planes. Therefore, this rock has undergone a $B \perp B'$-deformation ($B = b$; $B' = a$), the B′-deformation being weakly expressed in the fabric, however.

Blastomylonitic orthogneiss. — (plate I, fig. 2). Almost the same can be said for this rock. A complete biotite girdle around *b* has a strong 10 % maximum near *c* and smaller maxima corresponding to S_2 and S_3 (making angles of 41° and 35° respectively with S_1). In the section normal to *a* there is again a weak maximum corresponding to S_4 ($S_1 \wedge S_4 = 40°$) which very weakly represents the third or wrench-fault phase.

The quartz fabric has a girdle around *b*, with a definite minimum near *c* and maxima near the intersections of S_1, S_2, and S_3 with the girdle. A concentration of axes in the later S_4- and S_5-planes is scarcely visible.

Coarse-grained augen-gneiss. — (plate I, fig. 3). The micas have a complete girdle around *b*, with a very elongate 7½ % maximum near *c*. The width is explained by the augen texture of the rock. The two ends of this maximum correspond to S_2 and S_3, forming angles of 25° and 27° respectively with S_1 (plate IV, fig. 1). The section normal to *a* has a very incomplete girdle around $a = B'$ with some 4 and 5 % maxima corresponding to S_4, S_5, S_6 and S_7, forming angles of 27°, 25°, 47°, and 48° respectively with S_1. Here again the later crossed strain (B′) is weakly expressed.

The quartz girdle around *b* (= B) has minima between *a* and *c*, and maxima near *a* and also near *c*. The intersections of S_2 and S_3 with the girdle have 4 and 5 % maxima. The planes S_4, S_5, S_6, and S_7 belonging to the B′-crossed strain seem to contain very incomplete girdles.

Megacrystal biotite granite. — (plate I, figs. 4, 5). The first sample is a strongly linear rock having a very weak maximum of {001} of micas near *c* in the *b*-girdle. Two stronger maxima (5 %) corresponding to S_1 and S_2 ($S_1 \wedge S_2 = 81°$) are macroscopically visible in the sample. The B′-crossed strain also had an effect. The girdle around *a* (= B′) is very irregular. Two maxima correspond to S_3 and S_4 ($S_3 \wedge S_4 = 75°$).

The quartz girdle around *b* is complete; it has a minimum near *c* and strong maxima (5 %) near the intersections of S_2 and S_3 with the girdle. The crossed strain seems to have had no great effect on the quartz fabric: this may imply an incipient concentration in the S_3- and S_4-planes.

The second sample has a totally different fabric, being a planar rock, as is clearly proven by the strong maximum near *c* in the *b*-girdle of biotite. Other maxima correspond to S_2, S_3, S_4, and S_5, forming angles of 34°, 23°, 58°, and 78° respectively with S_1. The irregularities may perhaps be due to the small number of measurements. The incomplete biotite girdle around *a* (= B′) has 5 % maxima corresponding to S_6 and S_7 forming angles of 26° and 38° respectively with S_1.

The quartz fabric is rather peculiar. It seems to be a girdle around *b* although a very incomplete one, with a minimum near *c* and maxima near the intersections of S_1, S_2, S_3, and S_4 with the girdle, but not quite at the periphery. It could also be an incomplete small-circle girdle. The peculiarities could be explained by an incipient rotation of the quartz axes into the S_6- and S_7-planes of the later B′-deformation.

Muscovite granite. — (plate I, fig. 6). This is also a linear rock. The *ac*-girdle of muscovite is therefore a rather homogeneous girdle with many, but small, maxima corresponding to S_1, S_2, S_3, S_4, and S_5; S_1 forming angles with the other planes of 28°, 21°, 48°, and 49° respectively. The *bc*-girdle of muscovite is very incomplete, but here, too, there is some evidence of the B'-crossed strain (B' = *a*). Two weak maxima correspond to S_6 and S_7, forming angles of 41° and 35° respectively with S_1.

The quartz axes also show an *ac*-girdle with a relative minimum near *c* and maxima in the vicinity of the intersections of S_1, S_2, S_3, and S_4 with the girdle. There is some preferred orientation of the quartz axes along S_6 and S_7, as incomplete girdles.

Palingenic granites of Barbanza-type. — (plate II, fig. 1—6). Diagrams 3 and 4 are from one hand-specimen; the former is of the muscovite-type, the latter of the biotite-type. They are not oriented geographically, but the S_1 is the macroscopically visible foliation. The fabrics of the two are identical; it seems likely that the two types of rock have the same tectonic history. They have a complete *ac*-girdle of micas with some maxima corresponding to S_1, S_2, S_3, S_4, and S_5, the last four forming angles of 61°, 73°, 19°, and 26° respectively with S_1. There is also a *bc*-girdle, albeit a very incomplete one. Some of the maxima correspond to S_6, S_7, S_8, and S_9, forming angles of 18°, 26°, 39°, and 59° respectively with S_1. They also suggest a B'-crossed strain. The quartz fabric seems to have been strongly affected by the later B'-deformation. Planes S_6, S_7, S_8, and S_9 are loci of preferred orientation, although the girdles are not complete and sometimes even very incomplete. The older *ac*-girdle is also still visible. The S_{10}-plane, which is of the {hkl} form, seems to recur rather prominently but may be an interference pattern of the third deformation overprinted on the second.

Diagram 1 comes from the same exposure as the augen-gneiss. The two fabrics are identical, though the sample of the Barbanza granite has a more linear pattern with a relatively low maximum near *c*, for {001} of micas. Further, there are more maxima in the *ac*-girdle corresponding to S_2, S_3, S_4, and S_5, forming angles of 22°, 20°, 78°, and 75° respectively with S_1. The crossed strain B' (= *a*) is very definite: in the mica fabric the *bc*-girdle is almost complete showing some maxima (corresponding to S_6, S_7, S_8, and S_9), while the quartz pattern has almost lost the *ac*-girdle and acquired girdle orientation along the planes of the crossed strain: S_6, S_7, S_8, and S_9.

Diagram 2 of plate II contains mica and quartz patterns showing the effects of both deformations. The *ac*-girdle for micas is almost complete with maxima near *c* (S_1) and two others corresponding to S_2 and S_3 forming angles of 41° and 42° respectively with S_1. The girdle around *a* (= B') for micas is incomplete, with a minimum near *b*. Some of the maxima in this girdle correspond to planes S_4, S_5, S_6, and S_7, forming angles of 19°, 22°, 46°, 56° respectively with S_1. The pattern is rather asymmetrical, perhaps because the dextral N-S-striking slip-planes of the third deformation which caused the B'-pattern are better developed than those of the sinistral set. The quartz pattern consists of an *ac*-girdle, with a 4 % and a 7½ % maximum near the intersections of S_2 and S_3 with the *ac*-girdle. There are also concentrations in the S_4, S_5, S_6, and S_7-planes of the younger B'-crossed strain.

Diagram 5 has a complete girdle around *b*, for micas, with a maximum near *c* (S_1) and other maxima corresponding to S_2 and S_3. The girdle around *a* (= B') for micas is incomplete; some maxima are visible (S_1, S_2, S_3, S_4). The quartz pattern is very regular; an *ac*-girdle, with a minimum near *c*, and some weak maxima near the intersections of S_2 and S_3 with the *ac*-girdle. The girdles in the planes of the crossed strain: S_4, S_5, S_6, and S_7 are very well developed.

Sample 6 of plate II has an *ac*-girdle for micas, with a very elongate maximum near *c* which can be explained by the augen texture of this granite. Other maxima must be correlated to several planes: S_2, S_3, S_4 and S_5 forming angles of 32°, 25°, 65° and 55° respectively with S_1. The girdle around *a* (= B′) is complete here, with a minimum near *b*. The maxima correspond to S_6, S_7, and S_8, forming angles of 16°, 30°, and 42° respectively with S_1. The quartz axes have an orientation in an incomplete girdle around *b*, with maxima near the intersections of S_2, S_3, and S_5 with the *b*-girdle. Girdles along S_6 and S_8 from the B′-deformation are faintly visible.

Palingenic granite of Muros-type (medium-grained). — (plate II, fig. 7). The micas lie in a girdle around *b*, which is incomplete near *a*. There is no maximum in *c*, because this granite is more a linear than a planar rock. Some of the maxima correspond to S_2, S_3, S_4, and S_5, forming angles of 22°, 15°, 48°, and 47° respectively with a hypothetical S_1-plane. A girdle around *a* (= B′) for micas is very weak; it has some concentrations corresponding to the B′-crossed strain-slip planes S_6, S_7, S_8, and S_9, forming angles of 15°, 15°, 69°, and 44° respectively with S_1. These younger planes are better developed in the quartz pattern, although the quartz axes still have a weak girdle around *b*.

Palingenic granite of Muros-type (fine-grained). — (plate II, fig. 8). This rock possesses a foliation represented by a 5 % maximum near *c* in the girdle around *b* for micas. There are two other 5 % maxima, corresponding to S_2 and S_3 and forming angles of 42° and 40° respectively with S_1. There is also a definite girdle around *a* (= B′), caused by the later crossed strain. Two subsidiary maxima correspond to S_4 and S_5, forming angles of 28° with S_1. S_4 is more prominent than S_5, lying roughly parallel to the N-S-striking set of the latest deformation and also parallel to the preferred orientation of the wrench-faults. As a result, the fabric is asymmetrical. This is also visible in the quartz pattern. The girdle around *b* for quartz axes is incomplete. There are maxima near the intersections of S_2 and S_3 with the girdle. The quartz axes are also oriented in incomplete girdles along the younger S_4- and S_5-planes.

Conclusions drawn from the petrofabric analysis

1. Fabrics older than those with a NNW-SSE-striking B-axis have not been found in the samples.
2. The first and second phases of the probably "Hercynian" orogeny, yielding *ac*-girdles for quartz axes and mica cleavages, are not distinguishable in the fabric patterns.
3. The fabric patterns indicate a $B \perp B'$-deformation, B being the fold-axis of the first and second phase, B′ the slip-plane intersection of the third phase.
4. The B′-deformation is very poorly developed in the Complejo Antiguo.
5. The asymmetry in the girdles around *a* (= B′) can be explained on the basis of a stronger development of the N-S-striking wrench-faults or equivalent set of slip-planes of the third phase.
6. While the mica patterns are represented by strong B-girdle and very weak B′-girdles, the quartz pattern often show stronger effect of the crossed strain B′.
7. Quartz patterns show a regular development: in samples in which the third phase is very weak, as in the orthogneiss (plate I, fig. 2), quartz axes are arranged in an *ac*-girdle with a minimum near *c* and maxima near the intersections of {h0l} planes with the girdle. These planes are probably slip-planes in which the quartz axes are preferably concentrated in the direction of the slip; the strongest maximum is always near *a*. The later crossed strain caused the development of several {0kl}

planes in which the quartz axes were reoriented. Most of the quartz axes, formerly concentrated in *a*, have been transposed into the new planes. If this deformation had obliterated all traces of the older fabric, all the quartz axes would be concentrated in the new {0kl} planes in the direction of slip, giving rise to a *bc*-girdle (a girdle around $a = B'$), with maxima near the intersections of these planes with the new girdle. But in the region under discussion the crossed strain was not sufficiently severe.

CONCLUSIONS AND SUMMARY

A list of all the types of rock found in the region is given in Table IV. The oldest rocks in the region are Pre-Cambrian metasediments. The schistosity planes (S_o) in the schists and the S_i in the metablasts of the paragneisses have been caused by a probably Pre-Cambrian orogeny. Into these rocks a biotite granite and a megacrystal two-mica granite were intruded, and after these a large number of basic sills and dikes. As a consequence of the first "Hercynian" deformation (D_1) all these rocks were strongly foliated, causing a NNW-SSE-striking schistosity with sub-horizontal axes. The biotite granite became a mylonitic orthogneiss (afterwards recrystallized to a blastomylonitic orthogneiss), the megacrystal two-mica granite became a coarse-grained augen-gneis, and the basic sills became strongly foliated and lineated amphibolites. The schists and paragneisses were folded isoclinally; in the hinges of the folds an axial-plane cleavage was developed (fig. 2). During this phase of deformation the metamorphic grade must have been in the lower part of the amphibolite facies (quartz-oligoclase-biotite-muscovite-garnet-assemblage for the paragneisses; quartz-andesine-blue green hornblende-biotite-garnet-assemblage for the amphibolites). A pre-kinematic growth of andalusite took place in the schists of Abelleira; later they were altered to sericite (plate III, fig. 3).

There is preliminary evidence that the orthogneisses are Pre-Cambrian granites, deformed and metamorphosed during a Hercynian orogeny. Some "whole rock" Rb/Sr determinations have been carried out on a sample of orthogneiss by the Netherlands Foundation for Research in Isotope Geology (Director, Dr. H. N. A. Priem) at Amsterdam, but this work is still in progress and results will be published elsewhere.

After the first phase of recognizable deformation (D_1), intrusion of the "Early-Hercynian" megacrystal granite group took place. This granite contains xenoliths of the orthogneiss, paragneiss, and amphibolite, but apparently also early differentiation products of granodioritic composition. The megacrysts of potash-feldspar have a NNW-SSE orientation, probably due to flow parallel to the borders of the intrusion, but also parallel to the foliation of the country rock. A coarse-grained two-mica granite could be a later differentiation product, like the muscovite granite which almost always intruded the megacrystal biotite granite in sills parallel to the foliation or flow structure. Some aplites and very coarse-grained pegmatites also belong to this group. The relative position of this group is not yet clear. It is possible that the megacrystal biotite granite intruded as a palingenic granite from a very deep level into a much higher level which was in a lower stage of migmatization: metatexitic and diatexitic gneisses (see Table IV). But it is also possible that intrusion took place into a higher level which had not yet been reached by the migmatization, and that after the emplacement of the granite the front of migmatization reached the presently exposed area so that the granite could be older than the local migmatization.

In any case, after the first deformation (D_1) a large-scale migmatization took place. The schists in the eastern and western parts of the region were migmatized.

TABLE IV

DEFORMATIONS	ROCK TYPES	
Sub-vertical, N-S-striking cleavage; sub-vertical B′-axis D_3	POST-TECTONIC IGNEOUS ROCKS	Lamprophyre Granite porphyry Biotite granite of Pando
		Pegmatites, aplites, quartz veins
D_2 Sub-vertical, NNW-SSE-striking folation; horizontal B-axis	"Hercynian" PALINGENIC GRANITES	*c.* very fine-grained *b.* fine-grained *a.* medium-grained Muros-type two-mica granites *b.* biotite-rich type *a.* muscovite-rich type Barbanza-type two-mica granites Pegmatites, aplites Muscovite granite Coarse-grained two-mica granite
	"Early-Hercynian" MEGACRYSTAL GRANITE GROUP	Megacrystal biotite granite Granodioritic xenoliths
Sub-vertical, NNW-SSE-striking foliation: horizontal fold-axis D_1	"Early-Hercynian" ANATEXITES	Aplite Diatexites Metatexitic and diatexitic gneisses
Orientation of stress-field unknown. (relict $S_i = S_0$ in metablastic crystals) D_0	Pre-Cambrian ORTHOGNEISSES	Amphibolites Pegmatites Blastomylonitic orthogneisses and augen-gneisses
	Pre-Cambrian METASEDIMENTS	Paragneisses, schists and amphibolites

Areas with metablasts pass into metatexitic and diatexitic rock. In some places the diatexitic rocks are rather homogeneous fine-grained two-mica granites containing two-mica patches. These diatexitic rocks sometimes have an intrusive character. The coarse-grained augen-gneisses are also sometimes migmatized. The diatexites seem to have known an aplitic phase.

Subsequently, intrusion of the probably palingenic granites took place. The medium-grained two-mica granite of the Barbanza-type form a very long, but rather narrow, batholith-like intrusion. A muscovite-rich type preceded a biotite-rich type. Veins and dikes of these granites cut across the schists, augen-gneisses, and megacrystal biotite granite. Von Raumer (1963) investigated the Barbanza granites on the peninsula of Noya and found that they had a dome-like structure with nearly horizontal feldspar tablets (tablets parallel to {010}) in the centre, and dipping at the borders, parallel to the contacts. This has not been found in the region under discussion.

Near Muros, intrusion of the medium-grained two-mica granite of the Muros-type preceded that of the fine-grained variety. North of Sierra de Outes a larger body and some dikes of the fine-grained type are also found. All these palingenic granites often contain elongate two-mica patches, parallel to the foliation. Near the contact with these granites the schists often contain sillimanite. The granites themselves also often show sillimanite. Perhaps the second "Hercynian" phase of deformation (D_2), which gave the granites their NNW-SSE-striking, nearly vertical foliation, and sub-horizontal lineation, took place during the consolidation of these granites. In the paragneisses this tectonic phase is expressed in the cleavages with newly-crystallized muscovites lying parallel to the old foliation, in the orthogneiss in zones of finely-crushed quartz crystals.

Immediately after this, intrusion of pegmatite and aplite dikes and quartz veins, parallel or normal to the foliation, took place.

The last phase of deformation (D_3) could have been generated by a closely related stress-field. Its B′-axis, however, is vertical. Slip took place mainly along N-S-striking vertical planes. This stress-field continued to create the large N-S-striking dextral wrench-faults and the subordinate E-W-striking sinistral ones. This flattening phase (D_3) is concentrated in narrow zones. Shortly before this phase there was a period of relaxation and tension which probably caused the rocks of the Complejo Antiguo to sink into a "graben", so that these rocks represent a higher level of the orogene in which no or very little migmatization occurred.

Hereafter, the post-tectonic biotite granite of Pando intruded as a stock-like body, possibly by ring-fracture-stoping. Dikes of granite porphyry are probably related to this granite. The intrusion of lamprophyre dikes took place mostly along NE-SW-striking planes. Parga Pondal (1956) considers that they are of alpine age, but it is also possible that they belong to the Hercynian orogeny. Radioactive absolute age determinations may provide an answer to this question.

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