THE GEOLOGY AND PETROLOGY OF THE TROIS SEIGNEURS MASSIF

PYRENEES, FRANCE

BY

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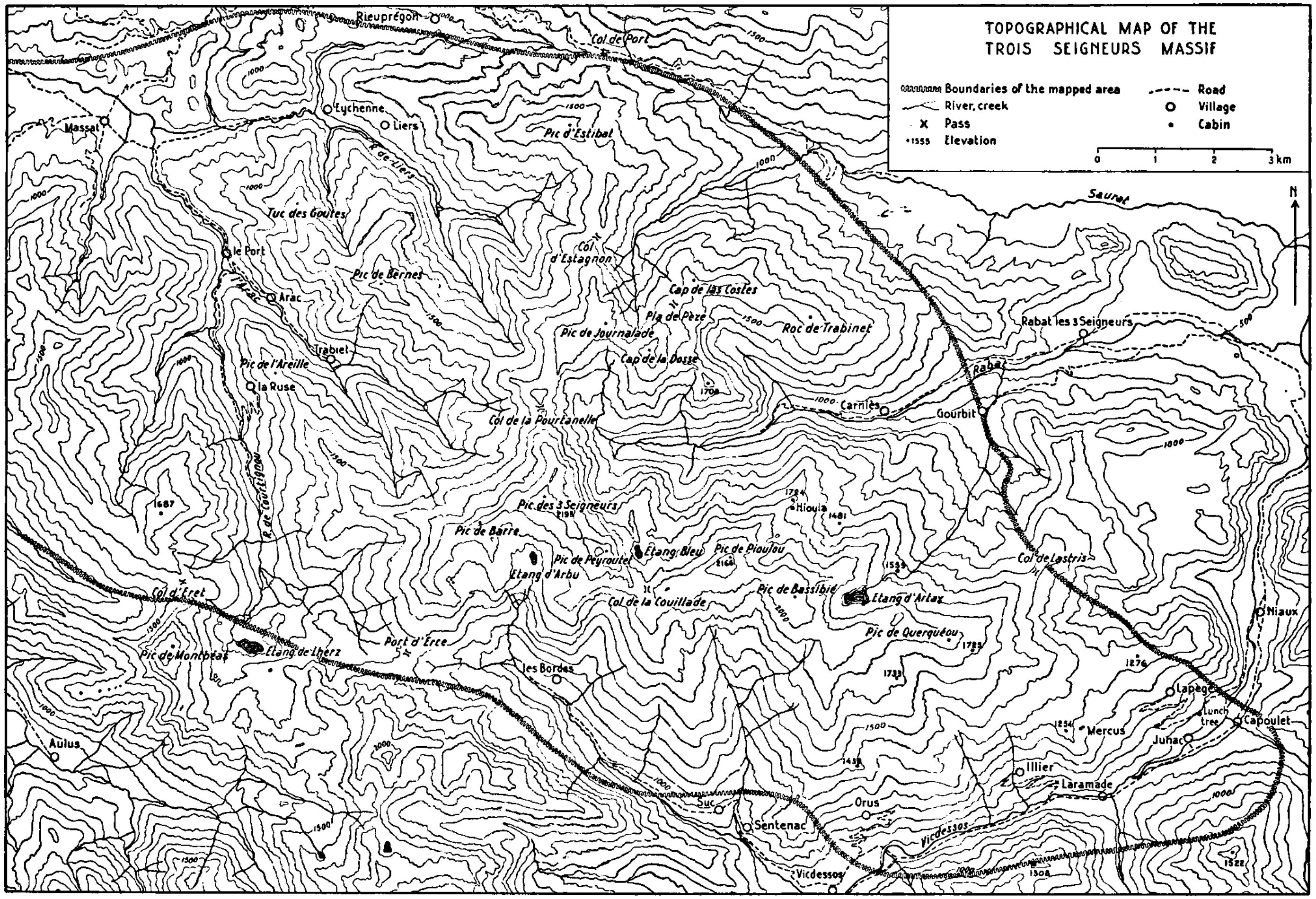

TOPOGRAPHICAL MAP OF THE
TROIS SEIGNEURS MASSIF
Boundaries of the mapped area
River, creek
Pass
Elevation
Road
Village
Cabin
0
1
2
3 km
N
Rieuprégon
Col de Port
Massat
Eychenne
Liers
Pic d'Estibat
R. de Liers
Tuc des Goutes
le Port
Pic de Bernes
Col d'Estagnon
Arac
Cap de las Costes
Pla de Pèze
Roc de Trabinet
Pic de Journalade
Trabiet
Cap de la Dosse
Pic de l'Areille
la Ruse
Col de la Pourtanelle
Carnies
Gourbit
Rabat
Rabat les 3 Seigneurs
Saurat
R. de Courtignou
Pic des 3 Seigneurs
Hioula
Pic de Barre
Pic de Peyroutet
Etang Bleu
Pic de Pioulou
Etang d'Arbu
Col de la Couillade
Pic de Bassibié
Etang d'Artax
Col de Lastris
Col d'Eret
Niaux
Pic de Querquéou
Pic de Montbéas
Etang de Lherz
Port d'Erce
les Bordes
Lapège
Lunch tree
Capoulet
Mercus
Junac
Aulus
Illier
Laramade
Suc
Orus
Sentenac
Vicdessos
Vicdessos

Fig. 1

INTRODUCTION

A. LOCATION AND MAIN PHYSIOGRAPHIC FEATURES

The Trois Seigneurs massif is one of the so-called North-Pyrenean massifs which in general form islands of Paleozoic and crystalline rocks in the midst of the main Mesozoic outcrop immediately north of the Paleozoic axial zone of the Pyrenees. It is situated SE of Foix in the French department of Ariège. Near the mapped area two other important North Pyrenean massifs occur viz. the St-Barthélemy massif to the east and the Arize massif to the north (see the geological map).

As fig. 1 shows the investigated region is rather mountainous. The highest mountain ridge is situated between the Port d'Ercé and the Col de Lastris, running from east to west. This ridge contains among others the following peaks: Pic de Barre (2007 m), Pic des Trois Seigneurs (2198 m), Pic de Pioulou (2166 m) and Pic de Querquéou. North of the Pic des Trois Seigneurs another important mountain ridge, containing the Pic de Journalade, runs northward to the Col de Port. The east side of the area is drained by the river Ariège and the west by the river Salat, both tributaries of the Garonne.

Relics of a Tertiary peneplain (GORON, 1942) are still preserved in the mapped area. A good example of this is to be seen between the Col de la Couillade and the Pic de Querquéou. Here the surface of the mountain ridge is flat. On its southern side a fairly wide and gently dipping slope occurs, which is terminated at an elevation of approximately 1500 m by the steep northern side of the U-shaped valley of the river Vicdessos. In the vicinity of the Cap de la Dosse similar features are also to be seen (see fig. 1).

The influence of former glacial erosion in the investigated region is still evident. The most important glacier, coming from the south, flowed through the Vicdessos valley. Near Auzat a tributary glacier which came from the Port d'Ercé joined the large one. Two other important glacier valleys are those of the Ruisseau de Courtignou (south of Massat) and the Rabat. On both sides of the latter, typical hanging tributary valleys occur. Their step-like long profile is always well-developed. The valley between the lake of Artax and Gourbit, for instance, has 5 rock steps. At the heads of the valleys, cirques occur. In several cases lakes are present in their floors, for instance, the lake of Artax, étang d'Arbu and étang Bleu. Late glacial fluvial terraces were observed in the Rabat valley north of Gourbit. In addition post-glacial fluviatile erosion is often evident, the rock steps in the valleys being sometimes deeply incised. Furthermore, in several places small canyons were observed in the beds of the Vicdessos and the Rabat rivers.

B. ROCKS OF THE TROIS SEIGNEURS MASSIF

In contrast with the neighbouring North-Pyrenean massifs, Carboniferous and Devonian rocks do not occur in this region. South and east of Massat sediments of *Silurian* age are exposed in an area which is elongated in WSW—ENE direction. These sediments consist of black or bluish black slates ("schistes carburés"), which are often graphite-bearing and ferruginous. In three localities THIÉBAUT (1956, p. 80, 81) has found graptolites in them.

In an east—west running zone north of the line between the Pic de l'Areille and the Cap de la Dosse and also NW of Liers, *Cambro-Ordovician phyllites* crop out. These are usually medium grey in colour, but often have a greenish tinge. Occasionally, intercalated quartzitic bands were observed. On the ridge immediately north of the Pic de Journalade there are important outcrops of quartz-rich greenish grey schists which are finely banded. Locally, intercalations of black graphite-bearing slates also occur, for instance, 700 m NW of the Cap de la Dosse. Graptolites were not found in these intercalations. The Cambro-Ordovician phyllites are in general very fine-grained and show cleavage folding. The direction of the cleavage strikes east—west, except west of the Cap de la Costes fault and NW of Liers (see the geological map). Near the biotite isograd (see p. 108) the phyllites become somewhat coarser in grain with the sericite flakes being often megascopically visible. These phyllites are described in Chapter I.

Mica-schists occur in the central and SE part of the investigated region, and in the vicinity of Liers in the northern part of the Trois Seigneurs massif. Layers of marble and quartzite occur in several places in these rocks.

A fairly narrow zone of *sillimanite-gneisses (migmatites),* averaging 200 m in thickness, underlies the mica-schists and is exposed between the Port d'Ercé and the cabin of Hioula.

In the high-grade mica-schists and the sillimanite-gneisses conformable bands of *quartz-dioritic gneiss* have been mapped.

Quartz-diorites occur structurally below the sillimanite-gneiss zone. They greatly predominate over the other rock types in the SE and NE part of the mapped area. In some instances smaller or larger complexes of sillimanite-gneiss and *"homogeneous" biotite-gneiss* are enclosed by the quartz-diorites. Furthermore they contain a considerable number of inclusions of greatly varying size, which consist of marble, amphibolite, quartzite, quartz-gabbro, etc.

Pegmatites and leucocratic granitic rocks are of frequent occurrence in the mica-schists, gneisses and quartz-diorites, particularly near the boundary between the mica-schists and migmatites. In the mica-schists and gneisses they tend to form sills, whereas in the quartz-diorites they have the form of parallel bands. Unconformable pegmatites are also common.

SE of La Ruse and west of Liers large bodies of *muscovite-biotite granite* and *muscovite-granite* respectively, occur in the mica-schists.

A batholith of biotite-granodiorite is present in the highest parts of the investigated area. It is also enclosed by mica-schists.

Small bodies of *chlorite-albite rock,* which occasionally enclose lenses of *chloritite,* occur in the quartz-diorites, gneisses, biotite-granodiorite and mica-schists.

C. INTERPRETATION

For approximately 10 years now the gneisses *) of the Pyrenees, occurring at the base of the Paleozoic rock series, have been regarded as having been

*) In this case the term gneiss is used in an extremely wide sense.

formed during the Hercynian orogeny; in other words, that they are syntectonic (HUPÉ, 1947, 1951; RAGUIN, 1951).

ZWART (1954) distinguished in the St-Barthélemy massif a series of old paragneisses, overlain unconformably by a series of migmatites. According to ZWART the original sediments which were later transformed into the old paragneisses, were of Precambrian age and suffered high-grade metamorphism at the end of this era, while the migmatites were originally Cambro-Ordovician sediments which underwent migmatization during the principal phase (sudetic) of the Hercynian orogeny.

GUITARD (1955) did not support this view however, and indeed supplied strong arguments in favour of the opinion that there is no unconformity between both series just-mentioned. He was able to prove moreover that the paragneisses and migmatites were formed during successive stages of the Hercynian metamorphism.

Independently of GUITARD, ZWART (1956) has pointed out, with reference to the St-Barthélemy massif, that synkinematic granitization has produced strongly foliated migmatites and gneisses; and post-kinematic crystallization, possibly going together with granitization, has produced quartz-diorites with a massive texture.

In the author's opinion there are no important reasons to doubt the statements and arguments of GUITARD and ZWART concerning the history of events which took place during the Hercynian metamorphism. These are in any case merely the application to the Pyrenees of the ideas which have been developed by other geologists elsewhere, e. g. MISCH and READ.

The present investigations have shown that a distinction between a synkinematic and post-kinematic phase of the Hercynian metamorphism holds true for the metamorphic rocks, gneisses and quartz-diorites of the Trois Seigneurs massif. It must however, be emphasized that in many cases the quartz-diorites of the mapped area were not produced as a result of statical recrystallization only.

Criteria for the recognition of rock types which have been produced through synkinematic and post-kinematic crystallization or granitization are given or summarized by SANDER (1950, part II, p. 295—306), MISCH (1949, pp. 691—696), READ and MEHNERT (1957, pp. 72, 73). Based on observations in the St-Barthélemy massif and the Canigou massif of the Pyrenees, GUITARD (1955) has also given a considerable number of criteria for the distinction of his early synkinematic "gneiss de la classe I" and late- to post-kinematic "Gneiss de la classe II".

Briefly we can summarize the most important characteristics of the rock types which were formed during the different successive stages of metamorphism.

In the field, the synkinematic gneisses and schists are recognizable by their well-developed foliation, presence of a distinct linear texture, sharp parallelism of felspathic bands, elongation of lenticular porphyroblasts in the direction of the foliation, and the lineation, and occurrence of boudinage structure. Rocks with these properties have already been described by many authors from other areas.

Under the microscope the rocks are distinguished by the presence of rotated porphyroblasts, strong parallelism of crystals, especially of micas and hornblendes (which usually show a form orientation) but also of quartz and felspar, bent crystals of mica in the folded portions of the rock, and the structure illustrated in fig. 26*b* by MEHNERT, 1957 (an example of paracrystalline deformation).

During the period of static recrystallization and granitization the parallel arrangement of the crystals becomes less distinct, in other words they are disoriented. Other features indicative of this process include corrosion of the different minerals, the formation of intimate intergrowths (see for instance quartz-gabbros p. 181), the development of polygonal arcs. Statically recrystallized and granitized rock bodies also show cross-cutting relations to the enclosing gneisses. In extreme cases rocks are formed, whose constituents do not show any preferred orientation.

An important argument in support of the thesis that the gneisses of the Pyrenees are related to orogenesis is given by RAGUIN (1946, p. 30). This author estimated that the depth of the migmatite front below the earth surface was of the order of 3000 m, if the migmatization took place after the deposition of the Dinantian, and much less if the processes were active during the Devonian or still earlier (see in this respect also ZWART, 1954, p. 118).

In table I the most important geological events which left their mark on the rocks of the Trois Seigneurs massif are schematically listed in chronological order.

TABLE I

Alpine orogeny	cataclasis			
Late Hercynian period of faulting (DESITTER, ZWART)	cataclasis	chlorite-albite rocks ?		
		intrusion of biotite-granodiorite intrusion? of muscovite-biotite-granite		
		post-kinematic (rheomorphism)		quartz-diorites, quartz-gabbros
Main phase of the Hercynian folding	metamorphism granitization	synkinematic	mica-schists	migmatites (sillimanite-gneisses) quartz-dioritic and homogeneous biotite-gneisses

CHAPTER I

MICA-SCHISTS

A. INTRODUCTION

In the central and SW part of the Trois Seigneurs massif mica-schists are exposed over a large area. The biotite isograd here runs in an east—west direction from the Pic de l'Areille to the Cap de la Dosse. To the south this series is partly limited by Mesozoic rocks, whereas further to the east it passes into migmatites.

In the vicinity of the Pic d'Estibat, both the biotite line (from Rieuprégon to the Tuc des Goutes) and the migmatite boundary run in a NE—SW direction. The mica-schist zone is here narrower than in the central part of the mapped area. These two separate mica-schist zones, originally formed a continuous unit and have been displaced in relation to one another by the Cap de las Costes fault.

The grade of metamorphism consistently increases from north to south. In order of their appearance the following types are present: *chlorite-sericite-schists, biotite-bearing chlorite-sericite-schists, biotite-muscovite-schists, anda lusite-biotite-muscovite-schists, sillimanite-schists.*

A continuous transition from chlorite-sericite-schists to migmatites occurs in a width of only 4 km north of the Pic de Pioulou. Everywhere else rather extensive bodies of biotite-muscovite-granite or biotite-granodiorite with an east—west trend interrupt the zonal sequence in the mica-schists.

During their emplacement the muscovite-biotite-granites exerted little influence on the enclosing rocks (see Chapter VI). The contact metamorphism of the biotite-granodiorite of the Pic des Trois Seigneurs on the surrounding rocks is, on the contrary striking both in the field and under the microscope (Chapter VII).

The schistosity is in general almost vertical or dips to the south. The strike is approximately east—west, except in the zone between the biotite-granodiorite of the Pic des Trois Seigneurs and the muscovite-biotite-granite of la Ruse and further, east of the eastern contact of both granite bodies and also west of the Cap de las Costes fault (see the geological map). The schists are isoclinally folded with pronounced cleavage folding. The schistosity is always parallel to the axial planes of the folds. A b-lineation, visible as a fine crumpling of the schistosity planes, is developed in many cases.

Often the schistosity is parallel to the sedimentary banding, but frequently they do not coincide.

B. CHLORITE-SERICITE-SCHISTS

These rocks exhibit a brown colour when weathered. In general they are finely schistose (phyllitic). Banding is very common. Bands, rich in chlorite and sericite, alternate with quartz-rich bands. Their thickness does not in general exceed 1 mm.

The chlorite-sericite-schists are always less fine grained than the Cambro-Silurian phyllites. The average grain size lies between some hundredths and some tenths of a millimetre. Often the quartz-rich bands are even-grained. Sometimes the grain size changes along the schistosity in one band. Successive bands may show different grain sizes. In several cases an inequigranular quartz mosaic occurs, in which few or many larger grains (several tenths of a millimetre) are embedded in a fine ground mass (0.1 mm or less). The quartz crystals in the quartz-rich bands are in general not elongated and oriented. In sericite-rich layers, however, this may be so. Conformable quartz lenses up to several centimetres thick are of frequent occurrence.

Two varieties of chlorite have been observed: 1) negative pennine in well-oriented flakes (length 0.1 to 0.2 mm) in the mica-rich bands; 2) clinochlore, which builds small oblong porphyroblasts (up to 1½ mm), with the cleavage oblique or perpendicular to the schistosity. Occasionally the clinochlore crystals are slightly deformed by a later cataclasis.

Sericite is in oriented flakes up to a length of 0.1 mm. In the quartz-rich bands they often show no preferred orientation. Frequently the schists are strongly folded. In the hinges of the folds the mica- and pennine crystals are bent. These constituents of the sericite-schists have for the largest part, preserved their synkinematic character.

Sericitized albite and adularia may be present in small amounts. Sometimes narrow cross-cutting veinlets with adularia can be seen.

Accessory constituents. Tourmaline occurs in every thin section. Two varieties have been observed: one with a pleochroism from brown to colourless and another from blue to colourless. In many cases the crystals have a blue core and a brown rim. Rutile builds either dark yellow brownish euhedral prisms or oval-shaped grains with a length of at most 0.1 mm. Anatase has been encountered in a schist rich in chlorite. Graphite is of frequent occurrence and often forms concentrations parallel to the banding. In one thin section five successive graphite-rich layers have been observed in a 2 mm thick quartz band, making an angle of 60° with the schistosity. Possibly these layers represent the trace of the original bedding. Zircon, apatite, pyrite and ilmenite are common, the former ore mineral is often partly altered into limonite and the latter into leucoxene.

The sericite-chlorite-schists are not indicated as such on the geological map. They occur in a zone at least 100 m wide outside the biotite isograde.

C. BIOTITE BEARING CHLORITE-SERICITE-SCHISTS AND BIOTITE-MUSCOVITE-SCHISTS

The grain size of these types of mica-schist is not very different from that of the sericite-chlorite-schists.

Biotite appears for the first time as small flakes with no preferred orientation in the quartz-rich bands. 100 m south of the biotite isograde the dark mica is also present in the muscovite-pennine bands. At the same time its grain size increases (0.1—0.2 mm, maximum 0.6 mm). The synkinematic character of this mica is usually evident in the biotite-muscovite-schists. Sometimes the biotite is partly altered into negative pennine, sagenite and titanite. Not far from the zone, where andalusite first appears, pennine recedes into the background and is probably secondary only.

The properties of the other constituents, remain the same as in the sericite-chlorite-schists. Only the grain size of muscovite and chlorite increases a little and the quartz crystals mostly show elongated sections in parallel arrangement. The transverse clinochlore porphyroblasts which are described above are also present.

Common accessories are tourmaline, zircon and apatite.

Close to the biotite isograd rutile may often be present in euhedral prisms or anhedral grains with a size up to 0.2 mm. More southward this mineral is locally present, but always in places where biotite is absent. The rutile disappears completely, when the andalusite zone is approached.

Ore may be an important accessory (up to 10 %). Hematite, ilmenite (eventually with leucoxene border) and pyrite have been found.

Lime-silicate rocks

SW of Trabiët approximately 200 to 300 m south of the biotite isograd a continuous band of marble has been mapped. This band can be followed over a distance of more than one kilometre and parallels the schistosity, which is almost vertical in this vicinity. Banding is always distinct. Blue grey marble layers, some millimetres to several centimetres thick, alternate with violet biotite-gneiss bands.

The grain size of the calcite in the marble bands varies (mostly 0.05 to 0.3 mm, at most 1.5 mm). In many cases the calcite crystals are elongated and show parallel arrangement. Equidimensional quartz grains (diameter mostly 0.1 mm, at most 0.2 mm) are regularly distributed. Locally thin biotitic seams (0.2 mm thick) have been found, of which the crystals are randomly oriented.

The biotite-gneiss bands consist of biotite, labradorite and quartz. In this rock type a fine banding is also distinct: biotite-rich folia alternate with quartzo-felspathic folia. In the latter the crystals are not elongated neither do they show parallel arrangement. Randomly oriented prisms of a pale green hornblende are sparsely distributed. Sometimes potash-rich felspar has been found, interstitial in the quartz-labradorite mosaic. Clinozoisite either occurs in fine-grained elongated aggregates which may surround a core of orthite or as an alteration product of plagioclase, in association with secondary adularia veinlets. Muscovite rarely forms pseudomorphs after plagioclase. Prehnite has been observed in or near cross-cutting calcite veinlets. It replaces plagioclase Titanite, zircon, apatite and in several instances also tourmaline, occur as accessories.

It is important to note that in these lime-silicate rocks a fairly basic plagioclase (labradorite) occurs at a relative small distance (200 to 300 m) from the biotite isograd.

D. ANDALUSITE-BIOTITE-MUSCOVITE-SCHISTS

In the most northern part of the zone of andalusite-biotite-muscovite-schists the grain size of the rock is hardly larger than that of the muscovite-biotite-schists. Southward the minerals gradually reach larger sizes.

Andalusite has been found 1) both north as well as south of the muscovite-biotite-granite of la Ruse; 2) in a zone about 1 km wide north of the biotite-granodiorite of the Pic des Trois Seigneurs, 3) in the neighbourhood of Etang Bleu; 4) south and east of the Cap de la Dosse; 5) in the vicinity of the biotite-muscovite-granite of the Pic d'Estibat. Between the Cap de la Dosse and the Rabat river and also much farther west, north of the Col d'Eret the quantity of the andalusite is at least as great as close to any of the three granite bodies. For this reason it is improbable that this mineral in the mica-schists has been produced mainly as a result of contact metamorphism of these granites. On the contrary, most of the andalusite in the Trois Seigneurs massif was associated with the Hercynian regional metamorphism.

The andalusite is always porphyroblastic. At a distance of 300 to 400 m from the biotite isograde the size is between 1 and 2 mm Deeper in the series the length averages 4 mm. Larger apparent porphyroblasts with diameters up to 1 cm consist of several individuals.

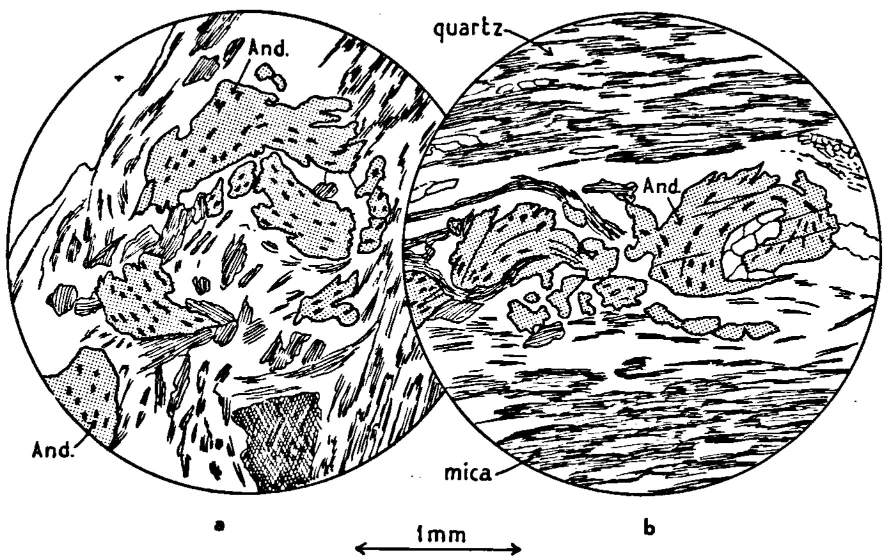


Fig. 2. a) Andalusite porphyroblast with S-shaped trends of ore inclusions.
b) Curved andalusite porphyroblast in mica-schist.

The crystals of andalusite always contain many inclusions of other constituents of the mica-schists: ore, especially ilmenite, quartz, mica. Their diameter is often only a fraction of the average size of the same minerals in the ground mass.

Synkinematic andalusite. The individuals are often elongated and lie with their longest axes parallel to the b-lineation. Mostly they push aside the surrounding mica folia. Sometimes strongly curved crystals occur, which may have a horseshoe-shape (fig. 2*b*).

It is very probable that a considerable amount of the andalusite porphyroblasts has rotated as a result of the Hercynian deformation. The trends of the inclusions are often S-shaped and they are not congruent with the structure adjacent to the porphyroblasts. The course of the inclusions mostly continues without interruption into the trends of the ground mass. A rather good example of a rotated andalusite is shown in fig. 2*a*. Features indicating rotation have been found only in thin sections normal to the b-lineation.

In the core of the horseshoe andalusites (see fig. 2*b*) quartz and micas form a granoblastic mosaic, whereas in other places both minerals often show parallel elongation. In the direction of the schistosity on both sides of the porphyroblasts there are often aggregates of quartz and mica. In these aggregates the crystals are coarser than elsewhere and show no preferred orientation. When at the same time the degree of pushing aside of the mica folia by andalusite is rather pronounced, it seems reasonable to suppose that we are concerned with stress shadows. It should be emphasized that the static andalusites are often surrounded on *all* sides by larger, randomly oriented quartz and mica crystals. Therefore not every coarser aggregate of biotite or quartz grains close to an andalusite porphyroblast, should be interpreted as a stress shadow.

Andalusites with wavy extinction are not common. A. HARKER (1939, p. 221) has already emphasized the uniform extinction of rotated staurolite crystals. This can be attributed to recrystallization lasting as long as or longer than the deformation; thus all the imperfections produced by the deformation could be healed immediately.

Sometimes porphyroblasts with S-trends tend to be idioblastic.

Static andalusite. Many andalusites have been found, which hardly interrupt the surrounding structures. In these the trends of the inclusions are congruent with the structures in their close surroundings.

Further andalusite crystals occur, which replace and include parts of mica-rich bands; the enclosed micas are without any preferred orientation.

In several cases the static andalusite individuals have pushed aside the surrounding mica folia. This is less pronounced than around the typical synkinematic porphyroblasts, but there is no reason to assume a fundamental difference in the behaviour.

The dimensions of the helicitic inclusions of unoriented static andalusites are frequently only a fraction of the mean grain-size of the matrix. In many cases the inclusions have approximately the same size as the components outside. Such porphyroblasts occur for example immediately north of the zone of sillimanite-muscovite-biotite rocks which surround the biotite-granodiorite of the Pic des Trois Seigneurs.

Static as well as synkinematic andalusite often occur in the same thin section and perhaps also in the same grain. I could not however, find typical examples of this mineral with a synkinematic core and a static rim. It is possible that the idioblastic shape of some rotated andalusites (see above) is a result of static recrystallization. Immediately north of the sillimanite-muscovite-biotite rocks (see p. 199) which surround the biotite-granodiorite of the Pic des Trois Seigneurs, a zone occurs in which only static andalusite has been found. Therefore it is probable that in this zone the andalusite has been formed as a result of the contact metamorphism of the granodiorite. Occasionally andalusite has been sericitized along irregular cracks and cleavage planes.

In association with pegmatites this mineral is either completely altered into sericite or partly replaced by muscovite (see below). C o r d i e r i t e with pleochroic haloes around zircon, is not frequent in the andalusite-rich zone. This mineral appears approximately at the same time as andalusite and has been found regularly down to the sillimanite-gneisses and quartz-diorites and also close to the biotite-granodiorite of the Pic des Trois Seigneurs.

In general this constituent builds small anhedral porphyroblasts with very irregular contacts. Sometimes the crystals are elongated parallel to the schistosity In most cases the mineral penetrates across the mica bands and replaces unoriented biotite crystals. Inclusions of other constituents are abundant, especially in the higher-grade parts of the rock series; they do not show preferred orientation. The cordierite has therefore a character different from that of synkinematic andalusite, and we are justified in concluding that most of the cordierite from the mica-schists is post-kinematic.

Alteration into pinite and a yellow brown serpentine-like mineral with a very low birefringence has frequently been observed.

In general the m u s c o v i t e plates are well-oriented and bent in fold hinges. In the quartz-rich bands however, orientation of the mica, is often less obvious.

B i o t i t e shows in the andalusite-schists the same relations as muscovite. The synkinematic character of this mineral is frequently well preserved, but it may tend to disorientation more often than the colourless mica. Partial alteration into pennine, sphene, sagenite and ore has frequently been observed.

Transverse porphyroblasts of c l i n o c h l o r e similar with those which are described on p. 108 and 109, occur in the northern part of the zone of andalusite-schists.

In the mica-rich parts the q u a r t z crystals are fine-grained (0.1 mm) and always elongated and oriented. In the quartz-rich bands the quartzes often show parallel elongation. Their sizes average 0.3 mm.

S i l l i m a n i t e appears first in the andalusite-schists in association with pegmatites (see below) as small fibrolite aggregates in muscovite, biotite or on the boundaries between quartz grains. The proportion of this constituent is still rather small.

Tremolite-phlogopite marble

In the andalusite-schists 1600 m ESE of the Cap de la Dosse a marble occurs which can be followed over about several hundreds of metres in the direction of the schistosity. Under the microscope laths of tremolite and phlogopite can be seen, regularly distributed in a granoblastic matrix of fine-grained calcite or dolomite.

E. SILLIMANITE-SCHISTS

Between the andalusite-schists and the migmatite boundary a rather wide band occurs in which sillimanite is common, whereas andalusite is not present. This is in contrast with other gneiss massifs of the Pyrenees, for instance the Arize massif in which the andalusite persists down to the migmatite boundary (H. J. ZWART, 1958).

From the zone of sillimanite-schists we shall chiefly describe that part which occurs on the south slope of the Rabat valley.

In the rock type under consideration s i l l i m a n i t e is usually developed as fibrolite. Irregular masses of fibrolite are mostly incorporated in biotite. In the cores of such masses shapeless crystals of sillimanite may be present. Pseudomorphs after biotite are of frequent occurrence. Many times I observed narrow folia of fibrolite which lie parallel to the schistosity in the biotite-rich layers. These folia run very often without interruption from the biotite through late transverse muscovites. It is as a rule clear that part of the fibrolite in the muscovite crystals has been replaced by the colourless mica.

In places where pegmatite sills are abundant small oblong fibrolite aggregates with a length of 0.5 to 1 mm occur independently in the quartz-mica matrix of the schists. In these masses tiny relics of biotite have been encountered.

Most of the sillimanite in the mica-schists is static as witnessed by its frequent tendency to form pseudomorphs after disoriented biotite.

Muscovite builds randomly oriented plates, replacing the other main constituents. Its proportion is as a rule not very great.

The relations and properties of the other constituents of the sillimanite-schists biotite, quartz, cordierite are essentially the same as in the andalusite-biotite-muscovite-schists.

Lime-silicate rock and cummingtonite-biotite-gneiss

In the sillimanite-schists on the south slope of the Rabat creek a band of cummingtonite-biotite-gneiss with a pronounced linear texture has been found. In thin sections parallel to the lineation very well oriented prisms of cummingtonite and laths of biotite can be seen in an aggregate of long-drawn and oriented grains of basic plagioclase and quartz. Perpendicular to this direction the shape of the crystals is always equidimensional; the sections of the cummingtonite crystals are beautifully six-sided. The plagioclase which is normally zoned, hardly attains an average diameter of 1 mm. Its index of refraction is much higher than that of quartz. The rare polysynthetic twinning is mostly very fine and rather indistinct, so that it is difficult to determine accurately the anorthite content. The cummingtonite is very often polysynthetically twinned. Quartz has always a wavy extinction The influence of static recrystallization in the gneiss appears to be negligible. In the quartz-diorites inclusions of a similar rock type have been found (see p. 172).

Not far from the gneiss just-described a lenticular body of a finely banded light yellowish rock occurs. Bands (1 to 2 mm thickness) consisting of clinozoisite and numerous small grains of clinopyroxene alternate with zones which contain quartz, garnet and clinopyroxene ($N\gamma/c$ appr. 44°) which form a typical granulitic texture (see for example HARKER, rev. ed. 1950, fig. 168 A). Near the clinozoisite-rich zones clinozoisite has replaced garnet of which well-developed pseudomorphs can be observed. Locally prehnite has been found in the clinozoisite. Sphene occurs as small oval-shaped crystals.

In this garnet-pyroxene-rock there is an original paragenesis of garnet, pyroxene and quartz. At a later stage of the metamorphism clinozoisite has replaced the garnet and also some clinopyroxene. It could not be proved that prehnite is still later than clinozoisite.

F. FELSPAR-BEARING VARIETIES

In many places in the mica-schists, homogeneous rocks with an important quantity of plagioclase have been found. These form bands usually a few decimetres in thickness but occasionally several millimetres.

P l a g i o c l a s e (oligoclase) . and b i o t i t e are as a rule very well oriented.

M u s c o v i t e is an accessory or may even be absent. Q u a r t z is present in small amounts. The grain size of these gneisses hardly differs from that of the enclosing mica-schists.

G. INFLUENCE OF PEGMATITES ON THE MICA-SCHISTS

In the central and SW part of the mapped area pegmatites are extremely rare in the northern part of the mica-schist zone. The first important concentration of pegmatite sills occurs in a continuous running zone from east to west at about 800 m south of the biotite isograd. Microscopical observations showed that the effect of the contact actions of the pegmaties on the enclosing mica-schists in this zone has been fairly thorough. The micas are often randomly oriented and quartz has an equidimensional shape. Small irregular porphyroblasts of potash-felspar are of frequent occurrence. Fibrolite occurs in small quantities near the contacts of the pegmatites. Andalusite is replaced by muscovite on a large scale. Immediately north of the zone the andalusite is almost completely sericitized.

The synkinematic character of the mica-schists has in general been well preserved on both sides of the pegmatite-rich zone. South of it, for instance in the Rabat valley, transverse muscovites replacing among others sillimanite and biotite are still rather common.

The static clinochlore porphyroblasts in the mica-schists which are described above (p. 108, 109, 112), are absent just where randomly oriented muscovites were observed for the first time in considerable quantities in the mica-schist series. South of the pegmatite-rich zone static clinochlore is never present. Consequently it is suggested that this mineral is connected with the formation of the pegmatites.

H. HYDROTHERMAL ACTIONS IN THE MICA-SCHISTS

a. Tourmalinization

South of Etang d'Arbu, half a kilometre WSW of the Pic d'Estibats and near Liers, examples of tourmalinization were observed close to pegmatite contacts. In the first locality more than 80 % of the rock consists of tourmaline. The banding of the original schists, however, can be seen quite clearly on the weathered surface. The tourmaline concentrations in the schist occur immediately adjacent to the contact. The pegmatite itself does not contain much tourmaline.

In the second locality a lenticular tourmaline-muscovite concentration ($1 \times 2\frac{1}{2}$ cm) was found close to a pegmatite sill. In one half of the lense the tourmaline prisms (average size 0.1×0.3 mm, maximum length 0.7 mm) are parallel to the schistosity. The tourmaline replaces both biotite and quartz. The dark mica is almost completely altered into negative pennine and ore. The other half of the lense is almost completely taken up by muscovite plates, showing no preferred orientation which also replace biotite and quartz. Locally relics of the brown mica occur in the colourless one. Thus tourmalinization is in this case associated with muscovitization and chloritization of the biotite. Elsewhere in the rock, outside the lense, completely fresh biotite occurs and chlorite is absent. West of Liers similar features have been observed.

b. Chloritization of the biotite in association with faults

Chloritization of the biotite can be evident far away from any pegmatite or aplite. In the mica-schists north of the Port d'Ercé, close to the fault which forms the southern boundary of the Trois Seigneurs massif, and also west of the Cap de las Costes fault, nearly all the biotite has been chloritized up to a distance of about 200 m from those disturbances.

c. Chlorite-albite rock

SE of Trabiët, approximately 380 m south of the biotite isograd, a leucocratic schist has been found, consisting mainly of albite, chlorite and some muscovite. At first glance through the microscope there seems to be no difference compared with a normal muscovite-biotite-schist, but closer inspection shows that this rock consists for the most part of albite instead of quartz. (See further Chapter VIII, p. 205.)

I. RELATION BETWEEN FOLDING, BANDING AND SCHISTOSITY

Features, corresponding to fracture cleavage, have been observed in the mica-schists. An example is given in fig. 3.

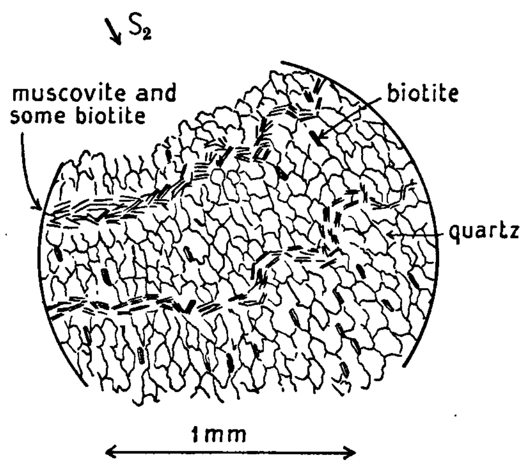


Fig. 3. Muscovite-biotite-schist with fracture cleavage.

Different successive stages of the formation of a tectonic banding, which may finally deviate strongly from the original sedimentary banding or an earlier tectonic banding, can be observed. An incipient stage is shown by a schist which has an obvious linear texture. In thin sections parallel to the lineation this schist is clearly banded; perpendicular to this direction the rock is more or less isoclinally folded. A second schistosity (S_2) is developed, which makes a small angle with the axes of the microfolds (fig. 4). Part of the quartzose bands are also folded, but an older banding is still visible, especially in unfolded areas where the schistosity crosses the quartzose bands under an angle of 45°.

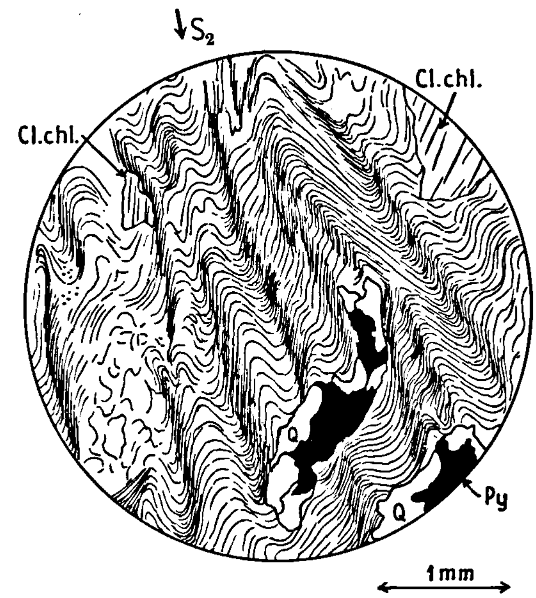


Fig. 4. Development of S_2 in folded mica-schist.
Cl.chl. = clinochlore, Py = pyrite, Q = quartz.

A further stage is represented by fig. 5*a*, where the newly developed schistosity obliquely cuts the older banding. A still further stage can be seen where banding and schistosity are already parallel (fig. 5*b*). It is

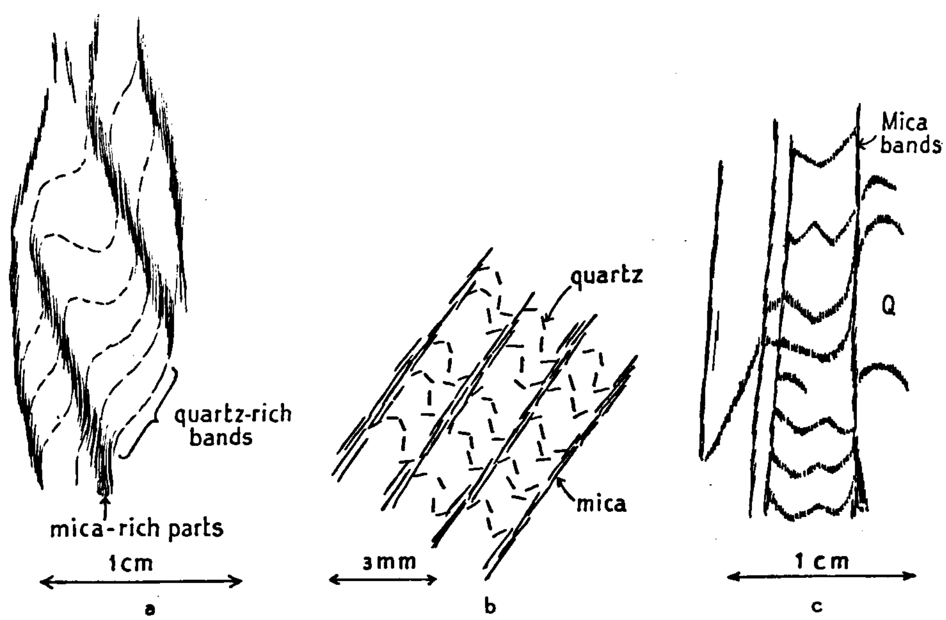


Fig. 5. Mica-schists showing different stages of the development of S_2 which cuts obliquely through an older banding.

striking that in this case the micas in the quartz-rich bands as a rule form polygonal arcs. Possibly the stress has not been so intensive in the newly formed quartz bands as in the mica-layers, resulting in a more random orientation in the quartzose bands, whereas in the mica-layers which have absorbed all the movements and acted as shearplanes, only oriented micas could form. If this assumption is correct, then the static character of the micas in the quartz-rich layers may have been accentuated during the post-kinematic phase of the Hercynian metamorphism.

A much further advanced stage is shown in fig. 5*c*, in which numerous undulating chlorite-mica-zones occur in the leucocratic bands. The cleavages of the mica and chlorite crystals parallel the schistosity. In this case the effect of deformation has been very thorough, whereas static recrystallization apparently has had no influence. It is probable that all these structures have been formed in successive stages of the synkinematic phase. The final stage (see fig. 5*c*) is not necessarily reached everywhere, but only where the deformation lasted the longest or was the most intensive.

K. CONCLUDING REMARKS

From north to south a progressive sequence of metamorphic zones can be discerned in the mica-schist series of the Trois Seigneurs massif: a biotite zone, an andalusite zone and a sillimanite zone. The presence of synkinematic biotite in the biotite zone and synkinematic andalusite in the andalusite zone proves that these two zones have already originated during the synkinematic phase of the Hercynian metamorphism. The sillimanite is in general post-kinematic and the sillimanite zone represents therefore a later stage of the metamorphism than both zones of lower grade which lie more to the north.

In the andalusite and biotite zone the influence of the post-kinematic phase becomes, among others, clear by the presence of static andalusite and statically recrystallized micas.

On the south slope of the Rabat valley cummingtonite and bytownite and also grossularite and clinopyroxene were found in layers which are enclosed by sillimanite-schists. These minerals are typical for the amphibolite facies and therefore it is justified to conclude that in this area the rocks have been under catazonal conditions during a certain stage of the Hercynian metamorphism.

In the andalusite zone marbles are rare. The presence of tremolite-phlogopite marble in the andalusite-schists east of the Cap de la Dosse may be an indication that the synkinematic paragenesis of the enclosing andalusite-biotite-muscovite-schists belongs to the epidote amphibolite facies (RAMBERG, 1948, p. 149).

The occurrence of labradorite in the marble which is found in the biotite-muscovite-schists SW of Trabiet is rather unexpected. In current literature the rocks which belong to the epidote amphibolite facies contain oligoclase and epidote minerals. The author thinks however, that it is unwarranted to place these rocks from the biotite zone in the amphibolite facies. ZWART (1954, p. 153) has also described lime-silicate gneisses in the mica-schists of the St.-Barthélemy massif, in which epidote and andesine or labradorite seem to be stable.

In the mapped area andalusite is the only synkinematic Al-rich mineral in the mica-schist series. Kyanite is not present at all, while staurolite is very rare. This last mineral has been found in only one locality near the Col de la Pourtanelle by A. LACROIX (1893—1895, p. 38, 39). In many other areas outside the Pyrenees, staurolite and kyanite are very common in mesozonal schists which surround high-grade gneiss massifs. Elsewhere in the Pyrenees, staurolite may be present in the mica-schists but in general it is not a common constituent.

Table II gives the probable fields of stability of the minerals of the three most important types of mica-schists.

TABLE II

FIELDS OF STABILITY OF THE MINERALS OF THE MICA-SCHISTS.

		Syn-kinematic	Post-kinematic	Near pegmatites	Retrograde metamorphism
MUSCOVITE-BIOTITE-SCHISTS AND ASSOCIATED ROCK TYPES	negative pennine	———	- - - -		———
	sericite	———	- - - -		
	biotite	———	- - - -		
	pale green hornbl.		———		
	labradorite	—?—	—?——?—		
	clinozoisite	?	?	———	———
	clinochlore			———	
	adularia			—?—	—?—
	prehnite			—?—	—?—
ANDALUSITE-MUSCOVITE-BIOTITE-SCHISTS AND ASSOCIATED ROCK TYPES	biotite	———	- - - -	- - - -	
	muscovite	———	- - - -	- - - -	
	andalusite	———	———		
	phlogopite	———	———		
	tremolite	———	———		
	clinochlore			———	
	negative pennine			———	———
	sillimanite			———	
	potash-felspar			———	
	adularia			———	———
	sericite			———	
SILLIMANITE-SCHISTS AND ASSOCIATED ROCK TYPES	bytownite	———			
	cummingtonite	———			
	grossularite	———			
	clinopyroxene	———			
	biotite	———	- - - -	- - - -	
	sillimanite		———		
	cordierite		———		
	muscovite		—?—?—	———	
	clinozoisite			———	—?—

——— period during which the mineral was probably newly formed.
- - - - period during which the mineral was statically recrystallized locally.

CHAPTER II

SILLIMINATE-GNEISSES, QUARTZ-DIORITIC GNEISSES AND HOMOGENEOUS BIOTITE-GNEISSES

Gneisses are of frequent occurrence in the Trois Seigneurs massif. They form both a continuous band below the migmatite boundary *) and complexes of varying dimensions in the quartz-diorites which predominate in the eastern part of the mapped area.

Three main types can be distinguished: A) sillimanite-gneisses, B) quartz-dioritic gneisses and C) homogeneous biotite-gneisses.

A. SILLIMANITE-GNEISSES (MIGMATITES)

a. Field relations

Sillimanite-gneisses predominate in a zone, about 200 m thick, between the mica-schists and the quartz-diorites. In addition smaller or larger complexes of the gneisses have been found in several places in the quartz-diorites below this zone. The most important outcrops are situated between Illier and Lapège and near the étang d'Artax. Occasionally small inclusions of sillimanite-gneiss with sharp contacts were observed in the quartz-diorites.

The mica-schists pass gradually into the underlying sillimanite-gneisses, the transition zone having a thickness of approximately 30 m. In this zone felspathized schists occur, in which a fine banding is often distinct. Felspathic folia, 1 to 2 mm thick, alternate with micaceous folia of similar thickness. Downward the composition of the folia becomes more and more exclusive while their thickness increases until typical sillimanite-gneisses are exposed.

The relations of the migmatites with regard to the quartz-diorites will be described in Chapter III.

b. Appearance and properties

In hand-specimen this rock type shows an alternation of quartzo-felspathic bands and biotite-sillimanite layers (fig. 6), which may have an exclusive composition. Muscovite is often present in randomly oriented plates. The thickness of the bands averages 2 cm, occasionally being as much as several decimetres. Their distribution is always irregular; in some places the leucocratic bands predominate, elsewhere the melanocratic layers. In many cases the contacts between both rock components are sharp.

The quartz-felspar bands may be medium-grained. Often they are coarse-grained and acquire a pegmatitic character. In one and the same leucocratic band however, the grain size may vary considerably.

*) The migmatite boundary parallels the trend of the foliation and usually dips at 50° to the north.

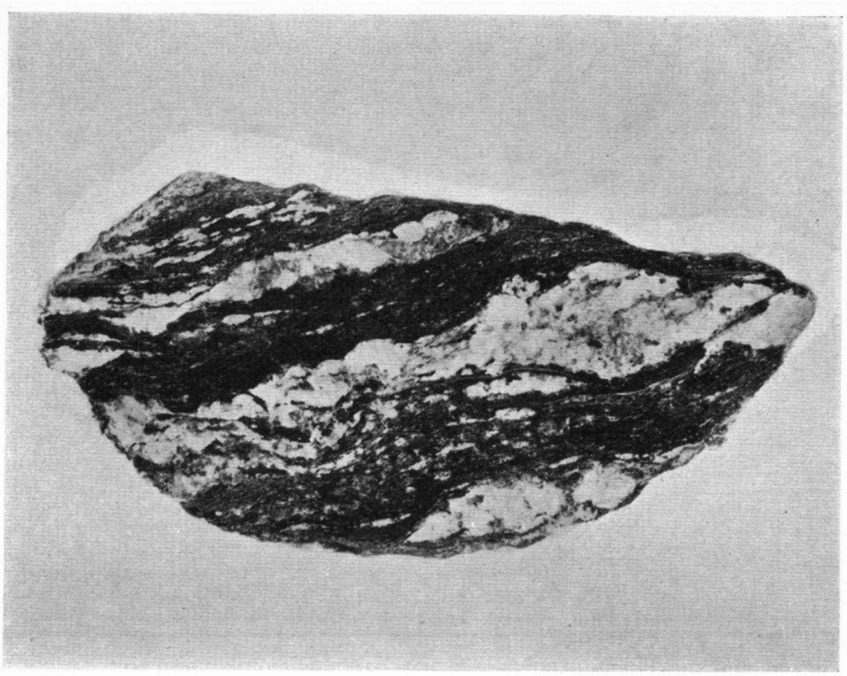


Fig. 6. Sillimanite-gneiss (migmatite) with boudinaged quartzo-felspathic veins (étang Bleu). $\times$ 6/5,

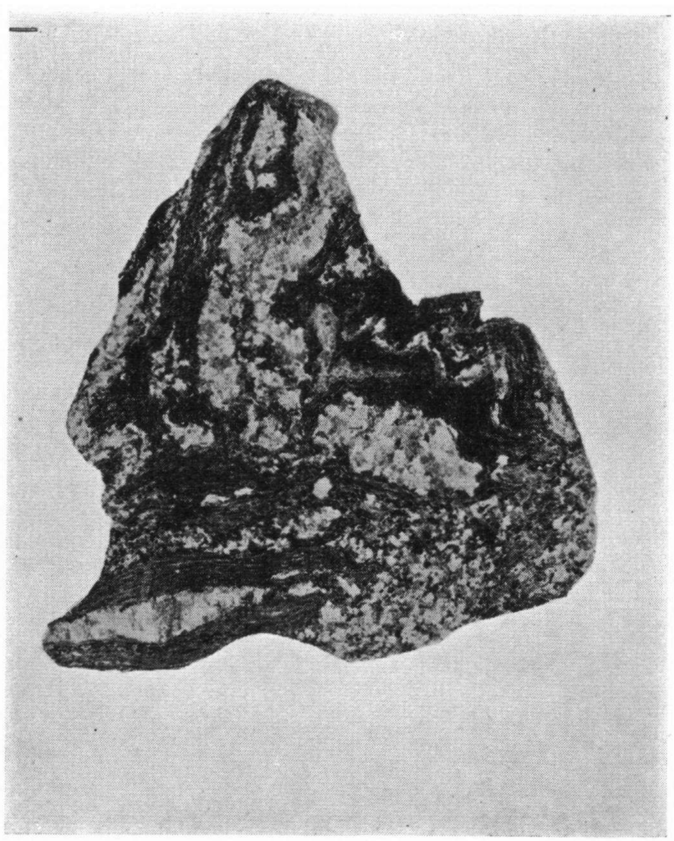


Fig. 7. Folded sillimanite-gneiss (north of the Pic de Pioulou). $\times$ 7/6.

Especially in the zone below the migmatite boundary but also elsewhere in the mapped area, beautiful examples of boudinage of the aplitic and pegmatitic components have been seen. Complicated folding of the gneisses and folding combined with boudinage also occurs frequently (fig. 7). The boudins always lie parallel to the fold axes.

Layers of amphibolite or weakly felspathized quartzite with a thickness of several decimetres are often present, these often show typical boudinage (fig. 8).

Sills of pegmatite, granite or leucocratic quartz-diorite are of frequent occurrence in the sillimanite-gneisses. They may contain many biotite-sillimanite schlieren. Often these schlieren are so abundant that it becomes

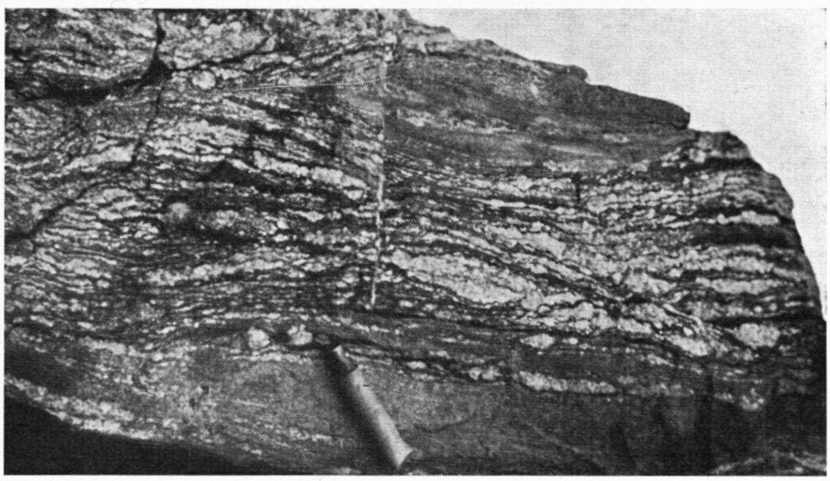


Fig. 8. Sillimanite-gneiss enclosing boudinaged quartzite (upper right hand side). (Photograph by H. J. ZWART)

difficult to decide whether the rock is a sill of pegmatite or a sillimanite-gneiss rich in quartzo-felspathic bands. These ambiguous rocks were encountered in many places.

Locally, the migmatites pass into finely banded gneisses, resembling the homogeneous biotite-gneisses which will be described below.

In many places sillimanite-gneisses have been found, of which both rock components have transitional contacts and also a less exclusive composition. Boudinage of the quartzo-felspathic bands has not been observed in this variety even in the folded parts of the rock series.

c. Microscopy

Under the microscope the rather exclusive composition of the two rock components of the sillimanite-gneisses was in many cases confirmed, the leucocratic bands consisting mainly of plagioclase and quartz and the melanocratic layers of biotite and sillimanite.

P l a g i o c l a s e (Oligoclase). In aplitic bands the grain size of this mineral varies between 1 and 4 mm. In coarse-grained bands the individual crystals may attain a length of more than 1 cm. In places where the felspar predominates over quartz, the crystals are elongated and show a parallel arrangement. Their contacts are wavy or indented. Where quartz is plentiful the plagioclase usually has a very irregular outline and does not then show preferred orientation. Antiperthitic intergrowts are of local occurrence. Normal zoning has been observed several times. Occasionally the plagioclase is slightly altered into sericite and kaoline.

In the leucocratic bands quartz occurs interstitially between plagioclase, or as smaller or larger grains in a mesh-work of plagioclase and biotite crystals. In the biotite-sillimanite layers the crystals are elongated parallel

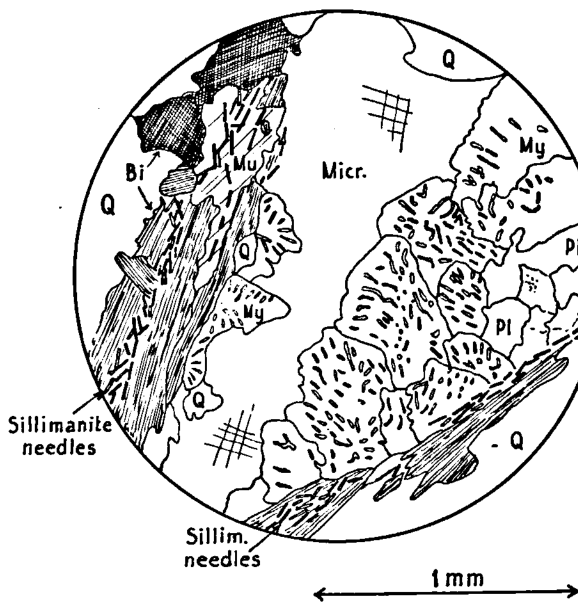


Fig. 9. Myrmekite replacing potash-felspar.
Bi = biotite, My = myrmekite, Pl = plagioclase, Micr. = potash-felspar.

to the foliation. In many cases the quartz penetrates between the mutual grain boundaries of plagioclase and biotite.

Potash-felspar, often showing microclinic twinning, is occasionally present, generally however in small amounts. Its grain size varies (diameter mostly 2 mm, but sometimes considerably more). The crystals always have an irregular shape. Porphyroblasts may occur which are sieved by numerous grains of the other constituents. The mineral is often microperthitic. Partial or complete replacement by chess-board albite has several times been observed. Transitions from vein perthite to largely albitized potash-felspar are common.

Myrmekite is of frequent occurrence. In some cases microcline crystals are partly replaced from all sides by myrmekite aggregates. These are often independent and apparently start from adjacent biotitic bands (see fig. 9). Quartz may penetrate between the boundaries of myrmekite and biotite and often shows optic continuity with the quartz vermicules in the albite. Another example of myrmekite which has been attacked "from the back" is shown in fig. 10. In this case the myrmekite vermicules show optic continuity with the replacing quartz. These features suggest that this mineral has been active during the formation of the myrmekite.

The grain size of biotite varies between 1 and 3 mm. In the quartzo-felspathic bands the plates are usually small and have irregular shapes; in the micaceous layers they are well-oriented, though with frequent exceptions. Polygonal arcs are well-developed in folded rocks. Only exceptionally the mica crystals in the folds are bent. Partial alteration into negative pennine is common.

Muscovite has an average size of 1½ mm. In contact with biotite

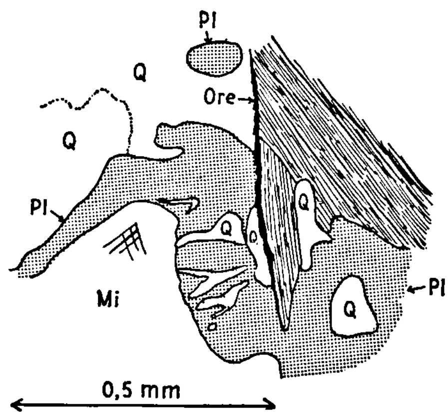


Fig. 10. Myrmekite attacked "from the back" by quartz.
Pl = plagioclase, Q = quartz, Mi = potash-felspar.

the mineral usually has straight boundaries. The colourless mica crystals generally have no preferred orientation. Replacement of randomly oriented biotite has frequently been observed. In the leucocratic bands the muscovite often shows a preference to occur in potash-felspar. The mica replaces this felspar. In many cases, quartz is involved in the formation of muscovite at the expense of the microcline and this results in intimate intergrowths between the three minerals. Based on the observed relations and the repartition of the muscovite it is concluded that this mica has originated in a late stage of the post-kinematic phase.

Sillimanite occurs as fibrolite and less frequently as prisms or needles. In the cores of the fibrolite masses irregularly shaped crystals of sillimanite can be observed. As a rule fibrolite is enclosed by biotite and forms beautiful pseudomorphs after this mica. In quartz and felspar the sillimanite is mostly developed as prisms. Masses of fibrolite with many small biotite remnants are often to be seen in muscovite. In this case three stages of the metamorphism are represented: 1) the stage during which only biotite was stable, 2) the stage when biotite was replaced by sillimanite, 3) the stage when the late muscovite took up the fibrolite.

Cordierite has a grain size of about 2 mm. In the biotitic bands the crystals are mostly elongated parallel to the foliation. The mineral often replaces unoriented biotite plates. In the quartzo-felspathic bands the individuals are more or less equidimensional. Cordierite is often partly or almost completely replaced by aggregates of finely intergrown muscovite and light green phlogopite. The cleavages of the crystals of the micas mostly lie parallel. Alteration into pinite and a light brown serpentine-like almost isotropic mineral has frequently been observed. Pleochroic haloes around zircon are common.

From its relationships to biotite it is concluded that most of the cordierite in the sillimanite-gneisses is post-kinematic.

G a r n e t was found as an accessory. It shows soms peculiar properties which will be dealt with under the description of the garnet-bearing biotite-gneisses (see p. 134). Other accessories include z i r c o n, a p a t i t e, i l m e n i t e, p y r i t e and h e m a t i t e.

Based on the microscopical investigations we can draw the following conclusions:

1) The influence of static recrystallization has been thorough in the sillimanite gneisses. This is indicated by the frequent occurrence of unoriented biotite and the presence of polygonal arcs in folded varieties.
2) Most of the sillimanite is post-kinematic.
3) Quartz has been active during successive stages of the metamorphism.
4) Muscovite has in general been formed late in the metamorphic history.
5) The leucocratic bands have in most cases a trondhjemitic composition.

d. Age of the migmatization

The frequent occurrence of boudinaged quartzo-felspathic bands and the observation that folding often appears in combination with boudinage, make it probable that the bands have been formed to a large extent before the termination of the Hercynian deformation.

Perhaps the migmatization started in *a late stage* of the synkinematic phase. Possibly the absence of foliation in the quartzo-felspathic bands indicates that the influence of the deformation in this rock component has already been less than during the formation of other types of synkinematic gneisses of the Pyrenees of which the leucocratic veins are strongly foliated (ZWART, 1954, p. 46, 47). It is also possible that migmatization has continued during the post-kinematic phase. As a result the variety could have been formed of which the two rock components have transitional contacts and a less exclusive composition.

The frequent occurrence of transitions between pegmatite sills and sillimanite-gneisses with concentrations of pegmatitic leucocratic veins may indicate that pegmatization was one of the aspects of the migmatization.

It is not probable that addition of alkali was very large during the formation of the rock type under consideration. Further, the rather exclusive composition of both rock components give reason to assume that besides lit-par-lit replacement (MISCH, 1949, p. 226—229) metamorphic differentiation was in many cases important during the formation of the gneisses (ZWART, 1956).

B. QUARTZ-DIORITIC GNEISSES

a. Occurrence, form and dimensions of the gneiss bodies

Bodies of quartz-dioritic gneiss are of frequent occurrence just above the migmatite boundary near Hioula and north of this cabin on the south slope and in the river bed of the Rabat. Three other bodies of this rock type have been mapped: on the migmatic boundary near the étang Bleu, in sillimanite-gneisses south of the col de la Couillade and in mica-schists north of Orus. Lenticular inclusions of quartz-dioritic gneiss occur in quartz-diorites near point 1555, and 1 km SE of Hioula along the track between this cabin and the lake Artax.

The dimensions of the gneiss bodies vary strongly. A maximum is attained by that of Hioula which has a thickness of 100 to 200 m and a length of almost 2 km. The smallest, occurring for instance in the river bed of the Rabat, are a few millimetres thick; they can be followed over distances of many metres in the direction of the foliation of the enclosing rocks.

b. Megascopical description

Elongated and oriented porphyroblasts of plagioclase with a length of several millimetres, and laths or plates of biotite with the same size are regularly distributed in a fine-grained matrix of biotite, quartz and a little felspar. The coarser crystals constitute the bulk of the rock, though locally the ground mass may predominate. Foliation and linear texture are usually distinct. In several bodies the porphyroblasts lie however, at random in an unfoliated fine-grained groundmass. In the large body near Hioula the quartz-dioritic gneiss is dominantly even-grained and mostly shows a pronounced linear texture.

In the occurrences south of the col de la Couillade and north of Orus, the gneiss locally has a migmatitic character: fine-grained felspathic layers (1 to 2 cm thick) alternate with others which are biotite-rich, medium-grained and of similar thickness. Linear texture is evident especially in the leucocratic layers. In the body south of the col de la Couillade several porphyroblasts of plagioclase have been found at most 1 cm in diameter; they tend to be euhedral and lie obliquely to the foliation.

c. Relations with the enclosing rocks

The quartz-dioritic gneisses always occur as conformable bands. Their contacts with the enclosing rocks may be either sharp or transitional. On the north side of the large body of Hioula the transition zone is some tens of metres wide. Approaching the country rocks from the gneiss the proportion of biotite increases until a mica-schist with rather abundant and well-oriented plagioclase porphyroblasts is exposed. Further to the north the quantity of porphyroblasts decreases, until at last a normal mica-schist is present. These transitional types may also occur independently as conformable zones in the mica-schists. On the southern side of the body of Hioula the contact is rather complicated. At about 10 m from the contact a regular alternation of mica-schists and quartz-dioritic gneisses has been observed. Further southward septa of sillimanite-gneiss replace the mica-schist layers.

They become more and more predominant until finally the quartz-dioritic gneiss disappears. The schistosity and the foliation in the three rock types is mostly parallel. In one case an inclusion of country rock has been found which lies somewhat obliquely to the foliation of the quartz-dioritic gneiss.

North and west of Hioula several large mica-schist septa occur in the large gneiss body. They are several tens of metres long and many metres wide. Their schistosity is always parallel to the foliation of the enclosing rocks. Disorientation with regard to the schists outside the gneiss was not observed. The contacts of these septa are either transitional, sharp or complicated.

In the Rabat valley, small and flat inclusions of mica-schist are often present in the quartz-dioritic gneiss zones. Their schistosity always parallels the contacts of the gneiss bodies. When the inclusions are regularly distributed and strongly elongated, the rock gets a migmatitic character. Such varieties are however, infrequent. Often one can observe a transition from small mica-schist inclusions to the locally predominating fine ground mass.

Inclusions of amphibolite or marble have been found in several places in the quartz-dioritic gneisses (see below).

d. Microscopy

Under the microscope the quartz-dioritic gneisses were seen to be in general inequigranular. Plagioclase, biotite and also quartz occur in relatively large crystals with an average size of 3 mm. Fine-grained aggregates consisting of biotite, quartz and a little plagioclase with a grain size of 0.3 to 1 mm are regularly distributed between the coarser crystals. The ground mass is in most cases subordinate to the medium-grained parts.

P l a g i o c l a s e. In the thin sections parallel to the lineation the coarser crystals are elongated and show a parallel arrangement. Their contacts are indented. The smaller grains have irregular shapes. Perpendicular to the lineation the crystals are equidimensional. The An content generally varies between An_{70} and An_{40}. The large body of Hioula contains more sodic plagioclase (An_{53} to An_{32}). Oscillatory zoning has frequently been observed. The basic cores are always distinctly euhedral, contrasting with the shape of the crystals themselves which are often anhedral or subhedral and only seldom euhedral. In several cases bytownite has been found on contacts with biotite. The bytownite which replaces the brown mica (see fig. 11) always makes up part of a more sodic plagioclase crystal (andesine or labrador). On the boundaries with quartz grains very thin rims of basic plagioclase may also be present.

Q u a r t z. The larger grains are often elongated and oriented. Contacts with the other constituents are irregular. Quartz may form inclusions in plagioclase in three different ways. 1) Small oval-shaped grains along the boundaries of the plagioclase crystals. 2) Inclusions of greater dimension with an amoeboid form in the cores of the crystals. 3) Poeciloblastic intergrowths (south of the Col de la Couillade); in small porphyroblasts the quartz inclusions are regularly distributed; in clearly zoned crystals the quartz pellets are only present in the basic parts; in plagioclase individuals with a less pronounced zoning the small quartz ovals are surrounded by basic remnants.

In the coarser parts of the rock b i o t i t e occurs in the form of laths and plates which are well-oriented. In the groundmass the crystals mostly do not show preferred orientation.

Apatite, zircon, hematite, ilmenite, orthite and garnet are accessories. In a few instances a blue green hornblende has been encountered.

The influence of cataclasis is observable in the quartz-dioritic gneisses.

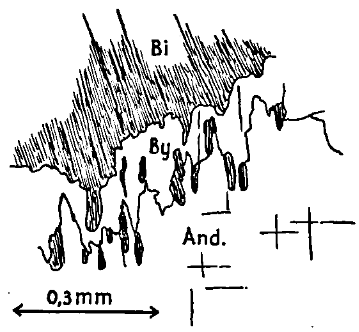


Fig. 11. Bytownite replacing biotite in quartz-dioritic gneiss. And = andesine, Bi = biotite, By = bytownite.

This is indicated by the undulose extinction of quartz, local occurrence of bent twin lamellae of plagioclase and occasional examples of deformed biotite crystals.

e. Marble- and amphibolite inclusions in the quartz-dioritic gneisses

Just below the ridge (east side) which runs from point 1724 to the Pic de Pioulou, at an altitude of 1810 m, an inclusion of marble representing an anticlinal hinge has been found. Along its contacts with the gneiss the marble is converted into lime-silicate rock about 1 dm thick. This rock type has an average grain size of 0.2 mm and is finely banded. Layers consisting of garnet, a little clinopyroxene ($N\gamma/c$ appr. 43°) and calcite alternate with bands which contain clinopyroxene, wollastonite, quartz and calcite. Secondary alteration products are completely absent.

Close to Hioula, 120 m north of point 1724 and north of Orus (on the ridge between this village and point 1429 at an altitude of 1370 m) enclaves of homogeneous amphibolite were found in the quartz-dioritic gneiss. These rocks are distinctly foliated and consist of green hornblende, plagioclase (labradorite) and some biotite. In the first-mentioned locality clinopyroxene and microcline are present in small quantities.

f. Pegmatites in the quartz-dioritic gneisses of Hioula

In the gneisses of Hioula unconformable pegmatites are of frequent occurrence. They generally follow irregular courses; their contacts are rather sharp. Dykes which run through from the quartzdioritic gneisses into the enclosing rocks have never been observed.

About 150 m west of Hioula there is a zone in the gneiss body in which the foliation is very obvious. In this zone cross-cutting pegmatites are schistose and it appears as though quartz and felspar have been smeared out in the direction of the foliation. The minerals of the gneiss do not show any traces of alteration and are indeed entirely fresh. Therefore it is unlikely that this zone is a mylonite zone which is later than the Hercynian metamorphism.

In other localities ptygmatically folded pegmatites have frequently been found.

g. Origin and age

Many features suggest a replacement origin of the quartz-dioritic gneisses: 1) gradual contacts with the enclosing rocks; 2) occurrence of inclusions, which do not show disorientation; 3) presence of a fine-grained groundmass which can be considered as a relic of pre-existing mica-schist; 4) marble and amphibolite occur in the gneisses as basic resisters; 5) transitional types between mica-schist and gneiss may occur independently in the mica-schists or at contacts of the gneiss bodies.

	a	b
SiO_2	62.60	58.60
Al_2O_3	15.82	16.34
Fe_2O_3	1.50	0.22
FeO	4.09	5.72
MnO	0.14	0.14
MgO	3.30	5.12
CaO	5.36	4.98
Na_2O	2.44	1.42
K_2O	2.40	3.16
TiO_2	0.81	0.94
P_2O_5	0.12	0.09
H_2O	1.60	3.71
	100.18	100.44

a) Quartz-dioritic gneiss 400 m WSW of Hioula.
b) Porphyroblast schist from the northern contact zone of the largest gneiss body.
Analyst Dr C. M. de Sitter—Koomans.

It can be supposed that the quartz-dioritic gneisses have been formed by basification of originally pelitic rocks (see Harry, 1954). In that case one would have to assume that next to addition of sodium, which is very probable in these gneisses (see the Na-K ratio), Ca, Fe and Mg have also been added. This is highly improbable since the percentages of MgO, FeO and Fe_2O_3 agree with those from normal mica-schists of pelitic origin. Our analyses of the quartz-dioritic gneiss are very similar to those which are published by Zwart (1954) from a variety of quartz-diorite in the St.-Barthélemy massif. According to this author the variety has been derived from lime-bearing pelitic rocks. It is possible that the gneisses under discussion have originated through a sodium metasomatism of such rocks. It is however, remarkable that the enclosing mica-schists do not apparently show any trace of influencing by the metasomatism; and therefore we have to assume that the metasomatising solutions have preferentially attacked these supposed lime-bearing pelites, leaving alone the pure pelites which apparently are only isochemically metamorphosed. Possibly the relics of bytownite represent an early stage of the metamorphism during which the metasomatism has not yet become active.

The development of foliation and linear texture, and the presence of distinctly foliated and ptygmatically folded pegmatites in the quartz-dioritic gneisses indicate that in general they are synkinematic.

In many cases the fine-grained groundmass is unfoliated. Probably this is a result of static recrystallization during the post-kinematic phase. The presence of rather large euhedral unoriented plagioclase porphyroblasts and also the local occurrence of a variety of quartz-dioritic gneiss showing no foliation might indicate that the metasomatism has locally continued after the termination of the Hercynian deformation.

C. HOMOGENEOUS BIOTITE-GNEISSES

a. Occurrence

Several different varieties of homogeneous and finely banded biotite-gneiss occur in the Trois-Seigneurs massif. South of Lapège, Hioula and the lake Artax, and also near the Pic de Querquéou such rocks are exposed. They are in general more leucocratic than the sillimanite-gneisses.

b. Linear muscovite-bearing biotite augengneisses

In the sillimanite-gneisses SW of Hioula a number of conformable sheets of rather leucocratic linear augengneiss have been mapped (see the detailed map). Their thickness varies between 2 dm and 20 m and they can be followed over a distance of many tens of metres in the direction of the strike. As far as has been observed the contacts with the enclosing rocks are knife-sharp.

Flat felspar porphyroblasts with a maximum length of 1½ cm occur in a fine- to medium-grained foliated matrix composed of felspar, quartz and biotite. The augen are mostly elongated in the direction of the lineation. The abundance of the porphyroblasts varies. Locally the gneiss is almost entirely made up of augen.

Microscopy. P o t a s h - f e l s p a r occurs as porphyroblasts with irregular contacts. Inclusions of the other constituents may be present in varying quantities. In the ground mass this mineral is in the minority compared with plagioclase. Microclinic twinning is frequent. P l a g i o c l a s e (oligoclase) is in elongated grains with parallel arrangement. Contacts of the crystals are indented or undulating. Q u a r t z occurs either interstitially between felspar or as larger elongated grains lying parallel to the foliation. It has corroded the other constituents. B i o t i t e occurs in streaks or trails, which in many cases bend around the felspar crystals. The laths and plates themselves are, however, never bent. Orientation of the brown mica is distinct, but there are many exceptions. Partial alteration into negative pennine has been observed. M u s c o v i t e is present in small amounts. It is late and replaces felspar and biotite. F i b r o l i t e is always enclosed by muscovite. Accessories are z i r c o n, a p a t i t e and o r e.

In many respects this type of gneiss resembles the linear muscovite-biotite augengneiss from the St.-Barthélemy massif which is described by H. J. ZWART (1954, 1958): 1) the mineralogical composition; 2) position in the rock series, near the boundary between the sillimanite-gneisses and mica-schists; 3) pronounced foliation and linear texture.

c. Homogeneous biotite-gneisses south of Hioula

Below the sillimanite-gneisses south of Hioula a zone, 80 m thick of biotite-gneiss is exposed which can be followed over a distance of 1½ km in the direction of the strike.

In hand-specimen a regular alternation can be seen of thin biotitic streaks

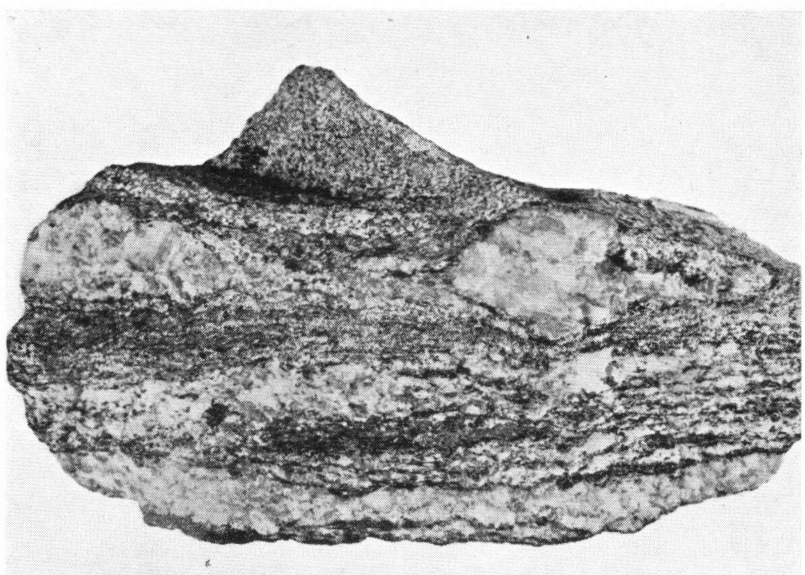


Fig. 12. Veined biotite-gneiss showing a migmatitic appearance (south of Hioula). Natural size.

with a thickness up to 1 mm, with somewhat thicker quartzo-felspathic layers. The frequency of the biotitic streaks may vary, resulting in more leucocratic and slightly more melanocratic varieties.

Conformable pegmatite and aplite veins are of frequent occurrence. Sometimes they are so abundant that the veined gneiss obtains a migmatic character. This may be obvious even in the hand-specimen (see fig. 12). Lenticular felspar augen, which are parallel to the foliation, have often been observed.

The foliation in the gneiss zone dips constantly at 45° to the NNW. Locally the rock is isoclinally folded.

Conformable lenticular inclusions and layers of slightly felspathized quartzite, banded lime-silicate rocks and homogeneous amphibolite are often present. Especially are quartzites abundant. Many of these show boudinage.

In many places the biotitic seams in the finely banded gneiss become more and more predominant and then the rock changes into a typical sillimanite-gneiss. The bodies of the latter gneisses are always elongated and lie in the direction of the foliation.

Towards the east the zone of biotite-gneiss changes very gradually into sillimanite-gneisses. The northern contact is similar. West- and southward the biotite-gneisses change into quartz-diorites. The disappearance of the foliation is accompanied by a small increase in the grain size of the rock. Irregular pockets and patches of rock in which the foliation is hardly or no more visible have several times been found in the biotite-gneiss.

Microscopy. Potash-felspar, with microclinic twinning, is in general less abundant than plagioclase. The mineral has irregular outlines. Plagioclase (oligoclase) often shows clear albite rims at the contacts with microcline. Partial sericitization of plagioclase has frequently been observed. The crystals of the felspars are in most cases elongated and show parallel arrangement. Quartz has undulating and crenulated contacts with the felspars. Laths and plates of biotite are in general oriented, though many exceptions occur. Alteration into negative pennine may give rise to sagenite. Muscovite is not abundant. It is late and replaces all the other constituents. Fibrolite occurs exclusively in the muscovite crystals. Other accessories are zircon, apatite and ore.

d. Garnet-bearing biotite-gneisses

In the SE part of the Trois Seigneurs massif garnet-bearing biotite-gneisses are common. These rocks predominate between Junac and Lapège. South of Mercus they frequently form conformable bands showing sharp or transitional contacts with the enclosing sillimanite-gneisses. East of the Pic de Querquéou an important outcrop has been mapped, which is completely surrounded by quartz-diorites.

Inclusions of amphibolite or quartzite have never been observed in the biotite-gneisses. ESE of Lapège several layers of marble are enclosed by the gneisses. One of the marbles can be followed over a distance of more than 300 m in the trend of the foliation.

The garnet-bearing biotite-gneiss is finely banded and strongly foliated (see fig. 13 and 14). Linear texture is locally evident. In many places the rock, together with its pegmatite sills (see below), is isoclinally folded (see fig. 15).

On foliation planes it can frequently be seen that the biotite crystals are disoriented. Many patches and pockets occur in which the foliation of the rock is rather vague or even absent (see figure 15 upper right).

Lenticular augen of varying dimensions are of frequent occurrence. They are always parallel to the foliation and push aside the surrounding biotite folia. Several times the porphyroblasts were seen to be elongated in the direction of the lineation.

Sills of pegmatite or leucocratic granodiorite, varying between 2 cm and one half metre in thickness, occur in many places. Locally they are boudinaged. In folded varieties, secretions of pegmatite or leucocratic granodiorite show a preference to occur in the hinges of the folds (see fig. 15).

Microscopy. In linear varieties, the minerals are always elongated and they show a parallel arrangement. The degree of elongation of the crystals

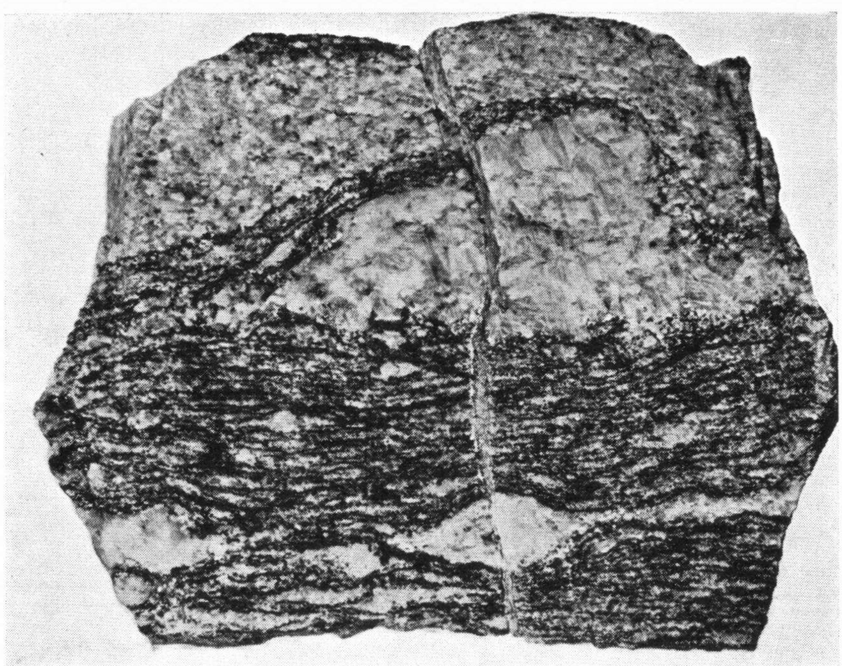


Fig. 13. Garnet-bearing biotite-gneiss. Natural size.

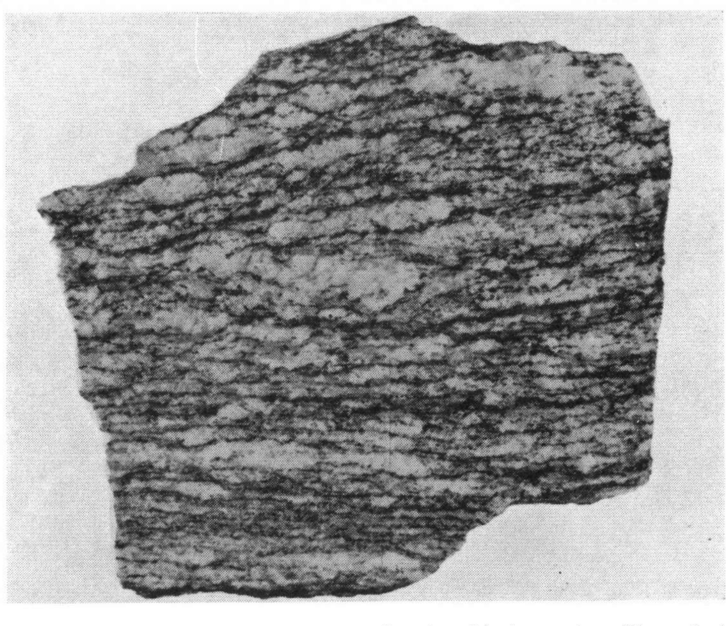


Fig. 14. Leucocratic variety of garnet-bearing biotite-gneiss. Natural size.

is more distinct in the slides parallel to the lineation than perpendicular to this direction.

Plagioclase (oligoclase) is the most important constituent, and is occasionally altered into sericite. Quartz forms discontinuous trails of small grains which are interstitial to the felspar crystals, but also occurs in the form of elongated grains or lenses of varying dimensions. In many

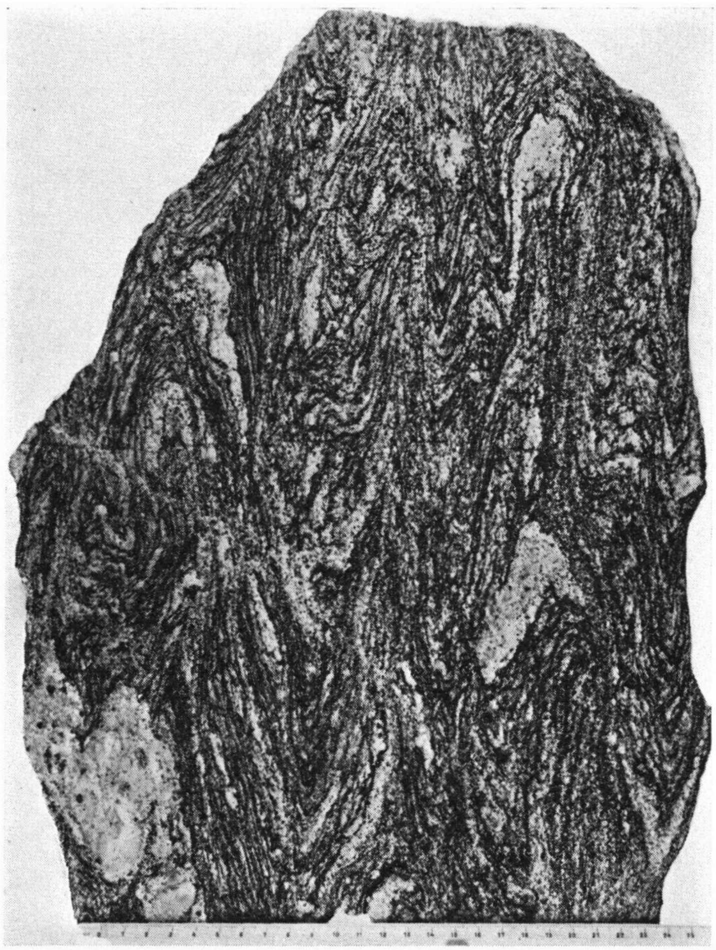


Fig. 15. Folded garnet-bearing biotite-gneiss with pegmatite in fold hinges.

cases the mineral penetrates between the grain boundaries of plagioclase and biotite. Contacts with the felspar grains are mostly crenulated. Potash-felspar often shows microclinic twinning. Microperthitic intergrowths have been observed. Myrmekite is of frequent occurrence; the quartz vermicules often show optic continuity with quartz crystals outside the felspar. Biotite forms folia of well-oriented and rather small plates and laths which are regularly distributed throughout the rock. These often bend around individuals of garnet and felspar. In such places the biotite crystals themselves are not usually bent. Garnet is equidimensional or elongated. It is only found in the biotitic folia. In many cases plagioclase penetrates between the boundaries of the mica and garnet and apparently replaces both minerals (see fig. 16). When quartz is lying close to garnet, the latter is nearly always surrounded by a thin rim of plagioclase. Alteration into negative pennine has been observed in cracks. Sillimanite is rare and forms prisms which are associated with biotite. Muscovite is present in small amounts. It

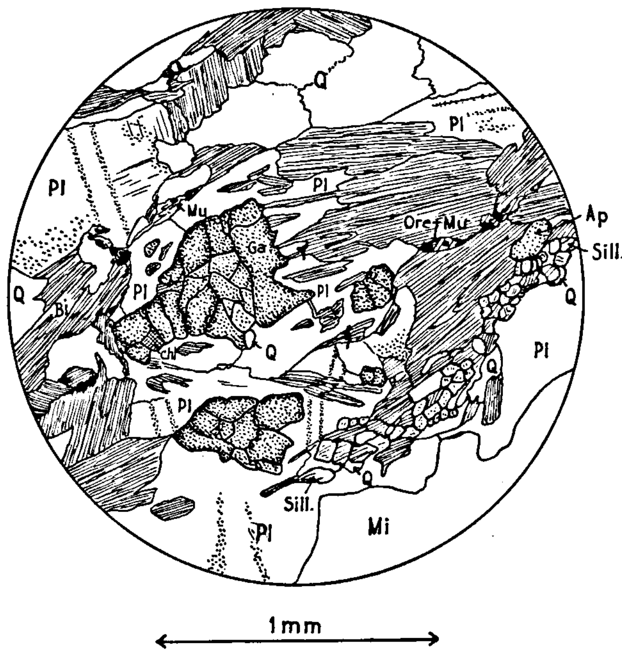


Fig. 16. Garnet and biotite, replaced (?) by plagioclase (garnet-bearing biotite-gneiss). Ap = apatite, Bi = biotite, Chl = chlorite, Ga = garnet, Mi = microcline, Mu = muscovite, Pl = plagioclase, Q = quartz, Sill = sillimanite.

is late and replaces biotite and potash-felspar. Apatite, zircon, ilmenite and pyrite are accessories.

In varieties without lineation the biotite is often only rudely oriented. Parallel arrangement of felspar and quartz may also be indistinct. In the patches without foliation the rock is identical with quartz-diorite. Many transitional types have been observed between the biotite-gneiss with linear texture and the patches of unfoliated rock.

e. Origin of the homogeneous biotite-gneisses

The following arguments are quoted in favour of a replacement origin of the biotite-gneisses: 1) the frequent occurrence of conformable layers of marble, quartzite and amphibolite; 2) transitional contacts, parallel or perpendicular to the strike of the gneiss bodies, with the adjacent rocks which are certainly of sedimentary origin; 3) the presence of septa of sillimanite-gneiss which are in structural continuity with respect to the enclosing biotite-gneiss.

It should be emphasized that the muscovite-bearing biotite augen-gneisses (p. 129) do not show properties which could point to formation by metasomatism of pelites or semipelites.

In the rock types under discussion foliation is distinct, linear texture is locally evident, boudinaged pegmatites are present, the crystals often show parallel arrangement and elongation in the direction of the lineation, folded varieties are of frequent occurrence. These features indicate that deformation has played an important part during the formation of the gneisses. Therefore it is concluded that they are synkinematic.

In varieties with linear texture the structure of the gneiss is identical with that of rocks which are regarded as having been formed as a result of paracrystalline deformation (see K. R. MEHNERT 1957). There is however, one important difference in the biotite-gneisses. Quartz seems to have been able to corrode the other minerals resulting among others in the development of crenulated contacts with felspar. It is suggested that the corrosion by quartz has started during a stage of the metamorphism when the influence of the deformation decreased more and more.

The influence of static recrystallization is in many cases obvious. Microscopical investigations showed that there are many transitions between distinctly linear and foliated varieties and the patches and pockets of unfoliated rock. In incipient stages of statically recrystallized biotite gneisses there is a slight disorientation of biotite. Furthermore, quartz becomes active and corrodes the other minerals and seems to be involved in the formation of myrmekite. In more advanced stages the parallel arrangement of the felspar crystals becomes less and less pronounced.

The biotite-gneisses are richer in felspar and poorer in biotite than the sillimanite-gneisses. If the former have been derived from pelitic rocks, the addition of alkalis would have been larger than in the late- to post-kinematic sillimanite-gneisses. Possibly the transfer of metasomatic solutions in the biotite-gneisses was facilitated by the effects of the deformation during the synkinematic phase.

Chemical analyses have not yet been prepared of the different rock types, which are described in this chapter. Therefore it is not yet possible to draw definite conclusions about the composition of the metasomatic solutions. Based on the general predominance of the plagioclase over potash-felspar, it is suggested that in the Trois Seigneurs massif synorogenic granitization was predominantly of sodium metasomatism-type.

CHAPTER III

QUARTZ-DIORITES

A. OCCURRENCE

Quartz-diorites greatly predominate over gneisses and resisters in the NE and SE part of the Trois Seigneurs massif. The largest complex which consists almost entirely of quartz-diorite occurs between Lapège, Illier and the Pic de Querquéou. This complex is indicated on feuille Foix (1950) of the geological map of the "Service de la carte géologique de France" as intrusive granite ("granite en massif circonscrit" of the same type as the biotite-granodiorite of Bassiès, the Pic des Trois Seigneurs, Ercé and Foix). This erroneous interpretation was corrected by THIEBAUT (1956) in a recent publication, in which he considers the exposed rocks as "granite d'anatexie" (JUNG and ROQUES, 1952). THIEBAUT distinguishes two other masses of "granite d'anatexie" (which I call quartz-diorite): one north of Orus, and another farther west near the Port d'Erce. The latter occurrence is however, a body of biotite-granodiorite of the same type as the biotite-granodiorite of the Pic des Trois Seigneurs (see the map and Chapter VII). Just below the sillimanite-gneiss zone near the migmatite boundary quartz-diorites often predominate. Elsewhere smaller masses or zones of typical quartz-diorite interfere with nebulitic quartz-diorite. Small patches of the rock type under discussion may occur in the homogeneous biotite-gneisses (see p. 131).

B. RELATIONSHIP TO THE SILLIMANITE-GNEISSES AND BIOTITE-GNEISSES

The quartz-diorites never penetrate the sillimanite-gneiss zone which occurs just below the mica-schists. Between the Port d'Erce and the étang Bleu and also east of the Pic d'Estibat the contact between the migmatites and the quartz-diorites is more or less conformable. SW of Hioula this is however, not so. The transition between the two rock types is always gradual. The width of the transitional zone is at most 10 m.

Near Lapège a zone of quartz-diorite showing unconformable contacts with the enclosing biotite-gneisses was observed (lunch tree). In other places, for instance east of the Pic de Querquéou, near the étang d'Artax, south of Mercus, elongated or shapeless bodies of sillimanite-gneiss or biotite-gneiss are completely enclosed by quartz-diorite. Small inclusions of sillimanite-gneiss and quartz-dioritic gneiss with sharp contacts are of local occurrence.

C. MEGASCOPICAL DESCRIPTION

In general the quartz-diorites are medium-grained rocks, whose constituents do not show preferred orientation. Their grain size can vary. This is visible both in a single hand-specimen (see fig. 17) and in different

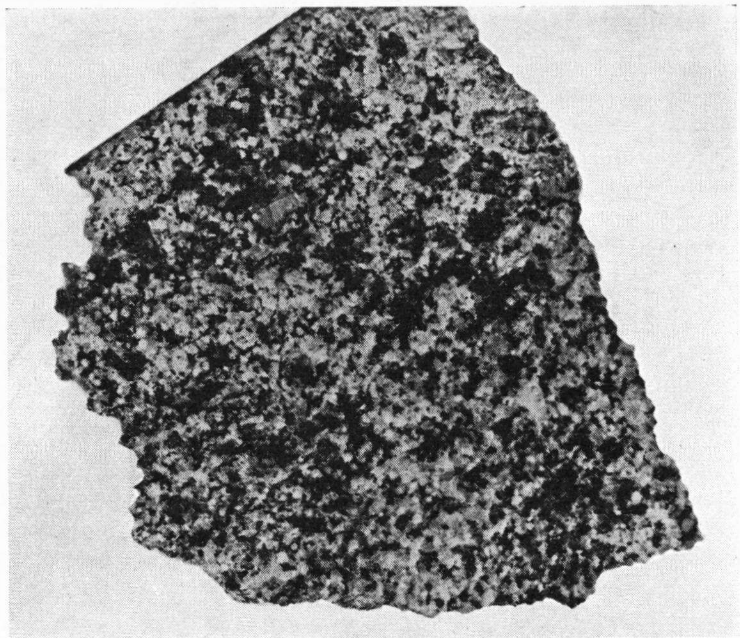


Fig. 17. Polished surface of quartz-diorite (350 m SE of Illier). Natural size.

Fig. 18. Quartz-diorite with felspar porphyroblasts, parallel leucocratic bands and rotated inclusion of biotite-bytownite-gneiss.

specimens of the same outcrop. Likewise in various exposures the rocks differ in coarseness.

Felspar porphyroblasts in great range of size have often been observed (see fig. 18). Sometimes they are very abundant, elsewhere, though rarely they are absent.

The distribution of the biotite is rather variable and often this is already evident in the hand-specimen (see fig. 17). Small patches and clusters of biotite are often randomly distributed. Parallel melanocratic schlieren are of frequent occurrence. In many places they are short and discontinuous, elsewhere they can be followed over at least several metres. Locally the course of the schlieren is very irregular.

Veins and sheets of pegmatite and leucocratic granitic rocks have been found in different localities. Their thickness varies between several centimetres and many tens of metres. Where these leucocratic bodies are frequent they show parallelism (see for instance fig. 18 and 28).

Although the quartz-diorites often have a nebulitic character, there are many large outcrops in which the rock is fairly homogeneous.

D. MICROSCOPICAL DESCRIPTION

Three minerals always predominate in the quartz-diorites. Quartz and plagioclase each generally occupy 25 % or more of the volume; biotite lags behind in relation to these two constituents, but mostly takes up 20 to 25 %. Variations in the distribution of the three main constituents are frequent. Muscovite is ubiquitous but is never present in great quantities. Its volume percentage rarely reaches 10. Potash-felspar occupies little space (at most 20 %) *) and occurs in most cases as an accessory. The distribution of this mineral is very irregular even in one thin section. Sillimanite and cordierite are less common than in the sillimanite-gneisses. Phlogopite is always associated with cordierite, from which it has been formed.

The quartz-diorites show in general a granoblastic structure.

P l a g i o c l a s e (oligoclase and rarely andesine) with an average grain size of about 2 mm shows mostly anhedral outlines. In almost every thin section however, there are a few plagioclase crystals, which tend to develop a subhedral shape (see fig. 19). The mutual grain boundaries of the plagioclase are in general straight or slightly undulating. The contacts with quartz are often irregular and embayed. Oval-shaped islets of quartz often lie along the contacts of the plagioclase crystals and show optic continuity with quartz lying outside. Sometimes this is not so.

Normal zoning is frequently evident. The cores of the crystals are only slightly more basic than the rims. Oscillatory zoning is well-developed in a quartz-diorite containing andesine (along the track Lapège Illier, immediately west of the first village).

A little less than half of the plagioclase shows twinning. Polysynthetic albite twins predominate; pericline twins are also present; complex twins, mostly Carlsbad, are rare. Twinning is more frequent in varieties with andesine, which occur in the above locality near Lapège and in a large outcrop east of the NE extremity of the lake Artax.

Antiperthite has often been observed.

*) In several cases the rock has a granodioritic composition.

Albite occurs in at least three different ways. 1) Thin clear albite rims are often present on the contacts between plagioclase and biotite. In several of these cases the albite has apparently replaced biotite. Such features have also been observed by CHENG (1944, p. 131, fig. 8). 2) In contact with microcline plagioclase frequently shows clear albite rims. Such rims are well developed in association with pegmatites along whose contacts the influence of microclinization has been important. 3) Plagioclase is in many cases partly altered into sericite and albite. This mode of albitization occurs regionally.

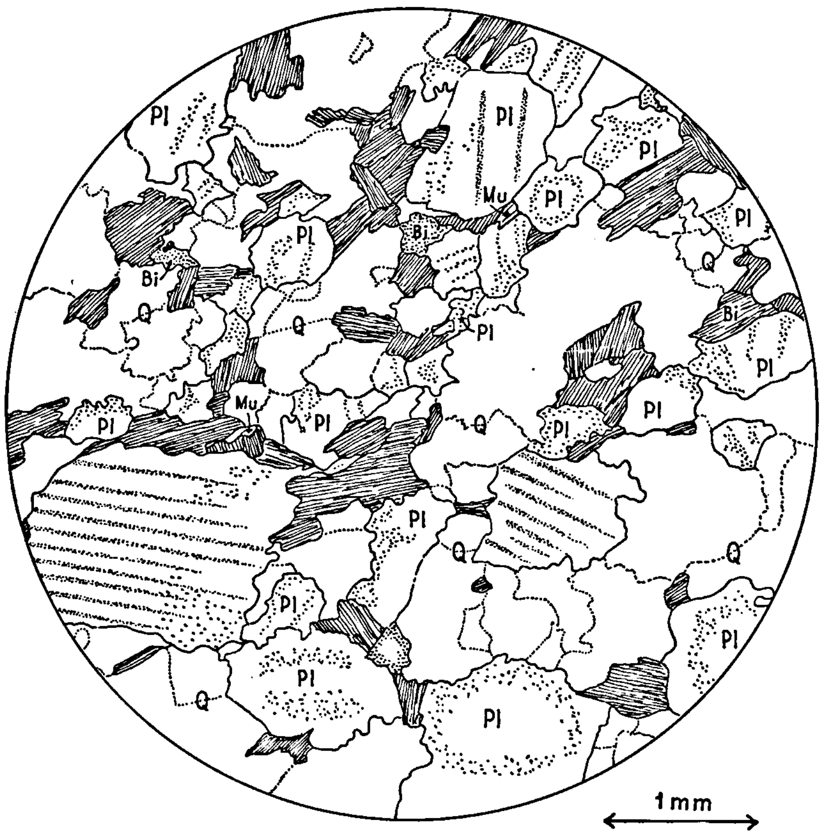


Fig. 19. Quartz-diorite.
Bi = biotite, Mu = muscovite, Pl = plagioclase, Q = quartz.

Along the contacts with adularia veinlets the plagioclase is also sericitized and albitized. These veinlets are associated with late unconformable pegmatites or with bodies of chlorite-albite rock.

The average grain size of potash-felspar ($2\frac{1}{2}$ mm) generally somewhat exceeds that of plagioclase in the same thin section. The crystals are mostly anhedral and rarely subhedral. Interstitial individuals always reach a large size (up to 1 cm). Microclinic twinning has been observed many times. The contacts with the other minerals are often very irregular. Intimate intergrowths with plagioclase are of frequent occurrence. Potash-felspar may enclose all the other constituents. The plagioclase inclusions show subhedral or euhedral outlines, they are mostly surrounded by thin clear albite rims. Along contacts of early post-kinematic pegmatites beautiful examples of microclinization can be seen. In these cases microcline may show a distribution as is illustrated in fig. 20.

The microcline has frequently a microperthitic structure. Besides typical exsolution perthite, also vein- and patch-and-vein perthite is present. In the patches and veins of albite chessboard structure has been observed.

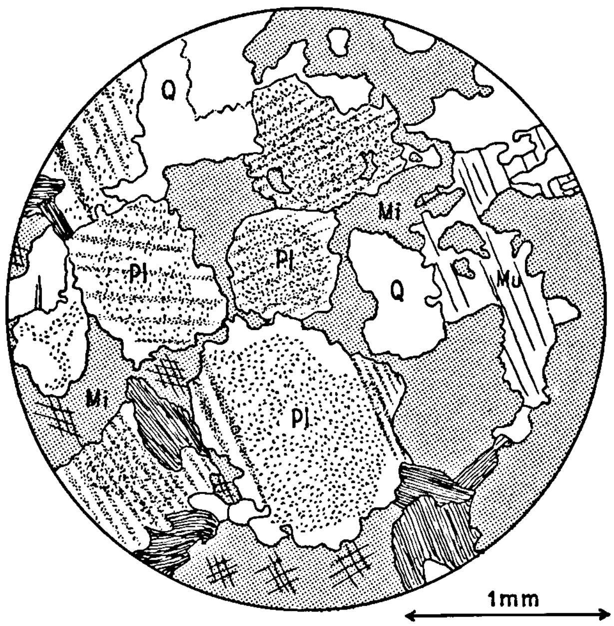


Fig. 20. Microclinized quartz-diorite. The plagioclase crystals have clear albite rims in contact with microcline.
Mi = microcline, Mu = muscovite, Pl = plagioclase, Q = quartz.

In many cases the potash-felspar is almost completely albitized. Myrmekite and clear albite rims of adjacent plagioclase crystals are often associated with these albite pseudomorphs.

A d u l a r i a. Immediately west of Lapège, a beautiful example of the result of potash metasomatism under hydrothermal conditions occurs in association with a late unconformable pegmatite. Under the microscope it can be seen that a great many of fine and irregular veinlets of adularia penetrate the quartz-diorite. The veinlets never show offset when they cut polysynthetically twinned plagioclase crystals. Their contacts with quartz are delicately indented. Biotite is also replaced by the adularia and is altered into negative pennine near the veinlets. Similar features have been observed along the immediate contacts with bodies of chlorite-albite rock (Chapter VIII). The plagioclase of the enclosing quartz-diorite is in these cases, however, strongly altered into sericite, kaoline and albite.

Myrmekite forms generally wart-like outgrowths of plagioclase penetrating microcline. Quartz outside the felspar crystals very rarely shows optic continuity with the quartz vermicules. This is in contrast with the observations in the biotite-gneisses and sillimanite-gneisses (p. 122, 133).

Quartz occurs as irregular grains of varying sizes, see for example fig. 19. When the mineral is not very frequent, it occurs interstitially.

Biotite builds plates with strongly corroded outlines. Often the mica forms small clusters. Elsewhere it may be distributed so as to suggest a paper torn into small pieces, whirling into the waste-paper basket. In many cases the biotite crystals tend to group themselves around plagioclase individuals (this is not very clear in fig. 19). Biotite-rich varieties of quartz-diorite mostly show a well-developed net-texture (D. FLINN, 1954). Preferred orientation of the brown mica is hardly ever evident, only in some biotite patches the plates may still be well-oriented.

The colour of the biotite varies, sometimes even in one thin section. When sillimanite is present reddish brown shades can be seen. Close to cordierite the mica is clear brown. In varieties of quartz-diorite with andesine sepia brown biotite is present.

Partial alteration into negative pennine or clinochlore is rather common. Prehnite lenses splitting the biotite have been found several times.

In clusters or schlieren the biotite crystals are often surrounded by rims of fine-grained ore and also small muscovite flakes.

Muscovite has strongly varying dimensions, but tends to form big plates, which may exceed a size of half a centimetre. In contact with quartz and felspar the colourless mica has very irregular outlines (see fig. 20, 21). The mineral shows a distinct preference to occur in or near microcline. Muscovite mostly penetrates along cleavage planes or in albite veins of vein perthite (see fig. 21). Therefore it can be concluded that the mica has been formed after the formation of the albite. Especially in plagioclase the incipient stages of replacement are distinct. During the replacement of the felspar by muscovite, quartz has been released. As a result intimate intergrowths between these minerals have been formed (see fig. 21).

In relation to biotite muscovite is usually cross-cutting. The contacts are often straight and parallel to the cleavage of the colourless mica. In patches, mainly consisting of well-oriented biotite plates, transverse muscovite crystals distinctly replace biotite and parts of fibrolite folia (see also p, 112). Several times it has been observed that the biotite is completely or partially surrounded by muscovite. The cleavages of the former mineral run without interruption into those of the latter.

Sillimanite is often an important accessory mineral. It forms separate prisms, either short and thick or long and thin, which are enclosed by any of the other constituents. Occasionally aggregates of sillimanite needles can be incorporated in muscovite and biotite. Elongated masses of fibrolite are of local occurrence. In a granodiorite south of Hioula the sillimanite prisms are partly altered into a light brown serpentine-like mineral with a very low birefringence.

Cordierite has been found in many places in the quartz-diorites of the mapped area. When occurring in quartz it shows very irregular outlines, but in biotite clusters the mineral is equidimensional or elongated. Inclusions of the other constituents are rare. Well developed muscovite-phlogopite pseudomorphs after cordierite have frequently been observed. These micas are always intimately intergrown with their cleavages generally parallel. Clear brown biotite outside the pseudomorphs is often connected with the phlogopite.

The transition between both minerals is gradual. Likewise, external muscovite runs through into the muscovite lamellae of the pseudomorphs. Possibly these pseudomorphs are contemporaneous with the regionally developed late muscovite. Cordierite is in many cases also partly altered into pinite and gigantholite. A light brown almost isotropic serpentine-like mineral occurs frequently in the pinite aggregates.

Accessories. Apatite, zircon and ore are common. Tourmaline, orthite and garnet are of local occurrence. Apatite and zircon

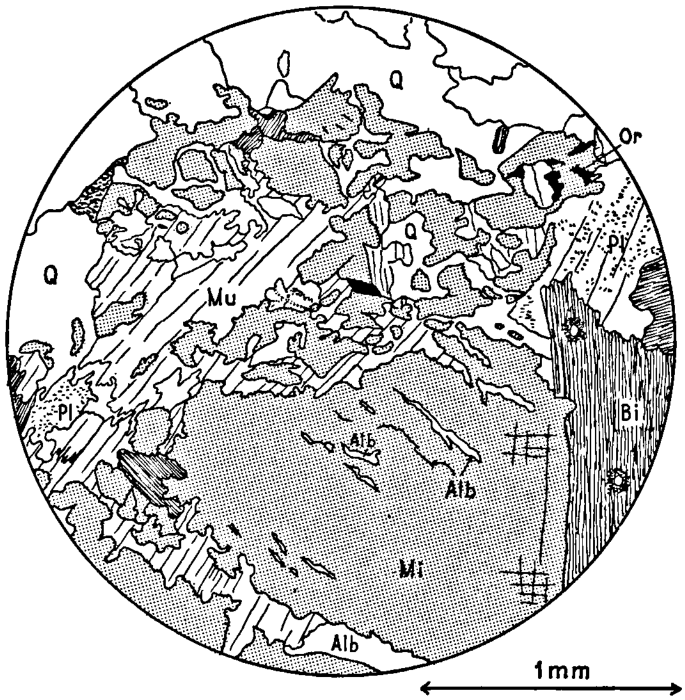


Fig. 21. Late muscovite replacing microcline and perthitic albite veinlets. Alb = albite, Bi = biotite, Mi = microcline, Mu = muscovite, Or = ore, Pl = plagioclase, Q = quartz.

often show an obvious preference to occur in biotite. In many cases the crystals of these accessories are taken up by quartz and plagioclase as a result of corrosion of the biotite.

In several outcrops tectonic movement is evidenced by the occurrence of a considerable number of slickensided joints. The quartz-diorites in these localities are strongly cataclastic. In the thin sections felspars show wavy extinction and the crystals are sometimes broken. Polysynthetic twin lamellae are bent in many cases. Sericitization of plagioclase is more obvious here than elsewhere. The micas are strongly deformed. Alteration of biotite into negative pennine is frequent, especially where grains of plagioclase have been pushed against biotite plates during the cataclasis. Newly formed negative pennine also penetrates the cracks and fractures of broken felspar crystals. Quartz is strongly undulose, mortar structure has locally been observed. In many cases this mineral has been recrystallized and penetrated fractures in felspar grains.

E. FLOW STRUCTURES IN THE QUARTZ-DIORITES

Bodies of amphibolite, marble, quartzite, etc. (see Chapter IV) in great range of size, are of frequent occurrence in the quartz-diorites. In most cases these rock types are banded or foliated.

The inclusions are often elongated and show flat contacts parallel to their banding or foliation (fig. 22). Their ends may be flat (for instance quartzites)

Fig. 22. Inclusion with flat contacts parallel to its banding in quartz-diorite. The foliation of the small migmatite body is not parallel with the banding of the resister (east of the lake of Artax).

but most are rugged. In other cases the inclusions have a very irregular shape (see fig. 23). Folded inclusions have frequently been found (see below).

In general the bodies of amphibolite, marble etc. do not form continuous and conformable layers as they do in the sillimanite-gneisses, homogeneous biotite-gneisses (see Chapter II) and mica-schists. They are randomly oriented their strike and dip are very variable, as well as the directions of the fold axes of the different folded inclusions. As a rule the schlieren in the quartz-diorite lie parallel to the contacts of the inclusions; and thus also parallel to the contacts which do not coincide with the bedding or foliation planes (see fig. 23).

Irregularly shaped inclusions, which lie with their longest dimension parallel to the prevailing direction of the schlieren in the quartz-diorites have been observed in many places. The banding in those bodies is distinctly oblique in relation to the foliation in the nebulite (see fig. 23, 26).

These observations show that we are concerned with flow structures. There are many examples of inclusions which have been moved relative to one another as a result of flow.

1) Firstly, reference must be made to an illustration which has been given by ZWART (1954, p. 113) from the St. Barthélemy massif. This author has concluded that both inclusions in the picture originally formed one layer which have been broken and have flowed in the quartz-diorite. Similar features have been observed in the mapped area.

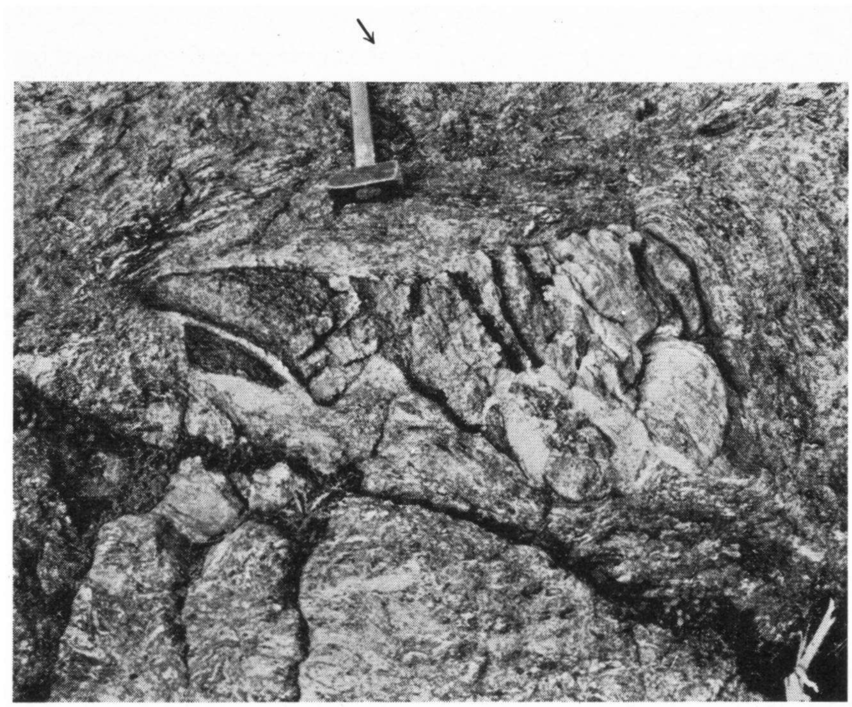


Fig. 23. Irregularly shaped inclusion of hornblende-bytownite-gneiss whose longest dimension parallels the prevailing trends of the biotite schlieren in the enclosing rock. The banding in the inclusion (the arrow indicates its direction) is oblique to the flow direction in the quartz-diorite. Note the small quartzo-felspathic lenses in the quartz-diorite (to the right of the hammer) (east of the lake of Artax).

2) East of the lake Artax an example can be given where two separate inclusions have collided. In the lower right-hand side of fig. 24 there is one flat body (the hammer lies parallel to the trend of its foliation). Another inclusion lies to the right of the centre of the photograph and is exposed parallel to its banding. Near the head of the hammer the enclaves touch one another. Detailed observation showed that these bodies do not form part of a fold. They are two separate inclusions, possibly derived from one layer which has afterwards been broken. The different pieces moved independently until they came again in contact.

3) Fig. 18 shows an example of disorientation of an inclusion of biotite-

bytownite-gneiss (see Chapter IV, p. 165). This body pushed aside two surrounding less melanocratic zones in the enclosing rock. The foliation planes to the left of the small body are slightly bent to the right, and those at the lower right-hand side to the left. Perhaps this is due to rotation of the inclusion in the plastic quartz-diorite which would imply that the body has been rotated in an anti-clock wise direction.

Fig. 24. Inclusions of biotite-bytownite-gneiss which have "collided" as a result of rheomorphism (east of the lake of Artax).

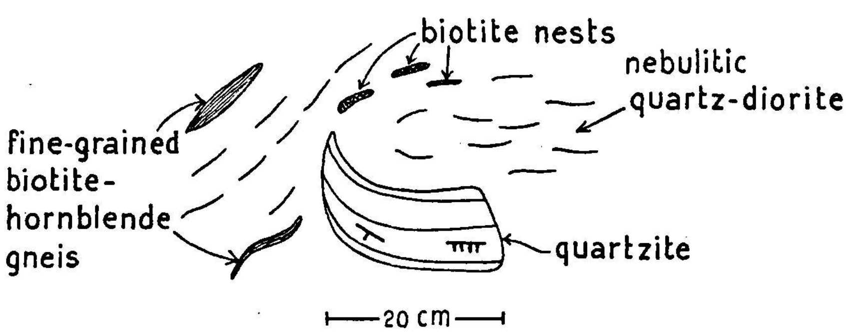


Fig. 25. Inclusion of previously folded quartzite which has rotated, dragging along in its wake two biotite nests (east of the lake of Artax).

4) Finally, another feature has to be discussed. Not far south of the "colliding" inclusions of biotite-bytownite-gneiss a quartzite inclusion (hornblende-bearing quartzite, p. 170) occurs in quartz-diorite. This small body is bent on one side and is drawn-out into a point (see fig. 25). This point

is directed to two biotite nests which are more than 5 cm long. I believe that this has to be explained as an example of the floating of a portion of an originally folded quartzite band. During this movement the inclusion has been rotated due to its shape, dragging along in its wake the biotite nests. Presumably the small body of biotite-hornblende-gneiss (p. 172) in the lower left-hand corner of the figure originally lay parallel with the lower contact of the quartzite. As a result of the flow it has floated to the left. It is improbable that the quartzite inclusion was bent as a result of the movement in the plastic quartz-diorite. In several cases slight bending of the ends of rotated inclusions has been observed as is illustrated in fig. 18. This feature is however, rare. There is a large number of rotated inclusions which are completely flat.

The features described above can be observed in most exposures of quartz-diorite in the mapped area.

F. GHOST STRATIGRAPHY NEAR THE LAKE OF ARTAX

In a NNW—SSE zone east of lake of Artax, which extends for a distance of more than one kilometre, inclusions of amphibolite and marble are much more abundant than elsewhere in the quartz-diorites. The relationship of these inclusions both to each other and to the quartz-diorites are similar to those described in the preceding pages, and we may safely conclude that the amphibolites, marbles and associated rock types originally have formed more or less continuous layers which have been broken into a large number of pieces, as a result of the flow in the enclosing rocks.

On the east side of this zone inclusions of striped amphibolite (p. 169) predominate with respect to other rock types. In the centre of the zone inclusions of hornblende-bytownite-gneiss and biotite-bytownite-gneiss (p. 165) are in the majority. On its east side marbles are most common. In its likely that this distribution in the zone represents a sedimentary succession, which suggests therefore that we are concerned here with an example of ghost stratigraphy. The picture which is revealed in the Trois Seigneurs massif however, differs completely from that which has been described by PITCHER (1953) from the Older granodiorite in the Thorr District of Donegal. In the latter area the inclusions of dolerite, quartzite, etc. generally show no disorientation.

G. BEHAVIOUR OF INCLUSIONS OF SILLIMANITE-GNEISS

Inclusions of sillimanite-gneiss are in general rare in the quartz-diorites. In the marble- and amphibolite-rich zone east of Artax they are more frequent than elsewhere; in this part of the area however, quartz-diorites still greatly predominate. The direction of the foliation in the separate gneiss inclusions is very variable. Often they are strongly folded. The foliation of several bodies is still parallel to the banding of adjacent inclusions of amphibolite and lime-silicate rock. In a number of cases the conformable character has been lost (see fig. 22).

Several important observations have been made which support the conclusion that the combined effect of flow and static recrystallization may result in the formation of quartz-diorite at the expense of sillimanite-gneiss. It was possible to distinguish several stages of such a process. In an incipient stage, several patches occur in the gneiss in which static recrystallization (disorientation of the micas) and homogenization has been more important than elsewhere. In a more advanced stage, large parts of the gneiss are homogenized though numerous elongated lenses, consisting exclusively of quartz and felspar or of biotite may still occur. These lenses are always to some extent disoriented. A rather bad example is given in fig. 22. In a still more advanced stage one can observe a quartz-diorite in which numerous short schlieren of biotite are present (lower side of fig. 26), accompanied occasion-

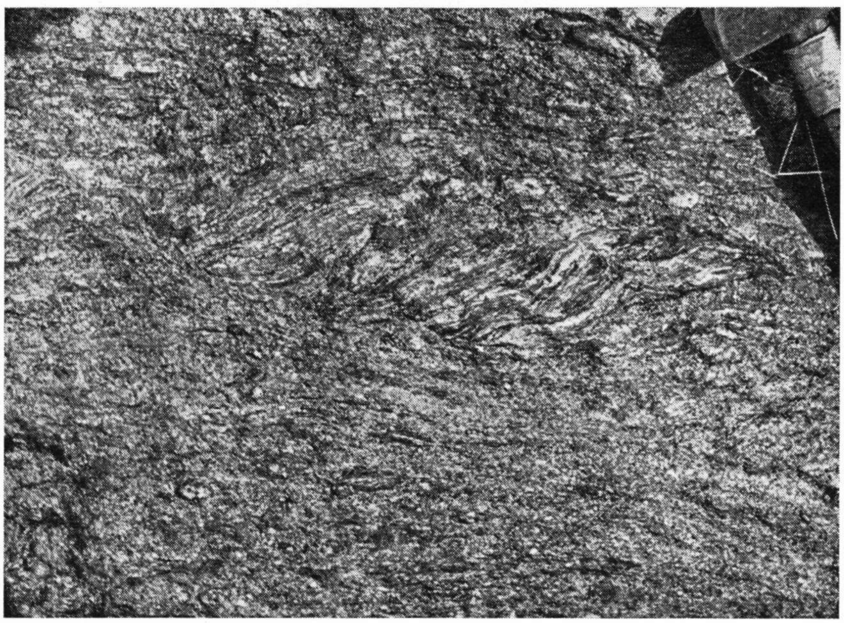


Fig. 26. Rotated migmatite inclusion in quartz-diorite, with short biotite-schlieren (east slope of the Pic de Bassibié).

ally by elongated lenses composed of quartz and felspar (fig. 23 to the right of the hammer). This last stage is especially well represented in the quartz-diorites. Presumably the biotite- and quartz-felspar bands of the most exclusive composition have been most resistent against the homogenization. In the small rotated migmatite inclusion of fig. 26 all stages of homogenization are also revealed.

H. QUARTZ-DIORITE IN HOMOGENEOUS BIOTITE-GNEISSES

In the biotite-gneisses, occurring south of Lapège, there are several important outcrops of quartz-diorite which enclose continuous bands of amphibolite. In many cases these bands are isoclinally folded. Features which indicate movement due to flow have not been observed. It is striking that the short biotite schlieren, which are so common in the quartz-diorite occurring elsewhere are rare and absent in most exposures.

Many patches of rock which is not or only slightly foliated have been found in the enclosing biotite-gneisses. They are identical with normal quartz-diorite, and never give any indication that they have pushed aside the enclosing gneiss.

Microscopical investigations showed that there are many transitional types between clearly foliated biotite-gneiss and quartz-diorite (see p. 134). It is therefore concluded that the last rock type can also be formed by static recrystallization only, at the expense of biotite-gneisses. The quartz-diorites which occur in the biotite-gneisses are mostly finer grained and somewhat less melanocratic than those in which flow structures are demonstrable.

I. SYNKINEMATIC RELIC STRUCTURES

Fold structures are often still recognizable in the bodies of amphibolite, marble, etc. Isoclinal folds are the most frequent. Sometimes the folds have

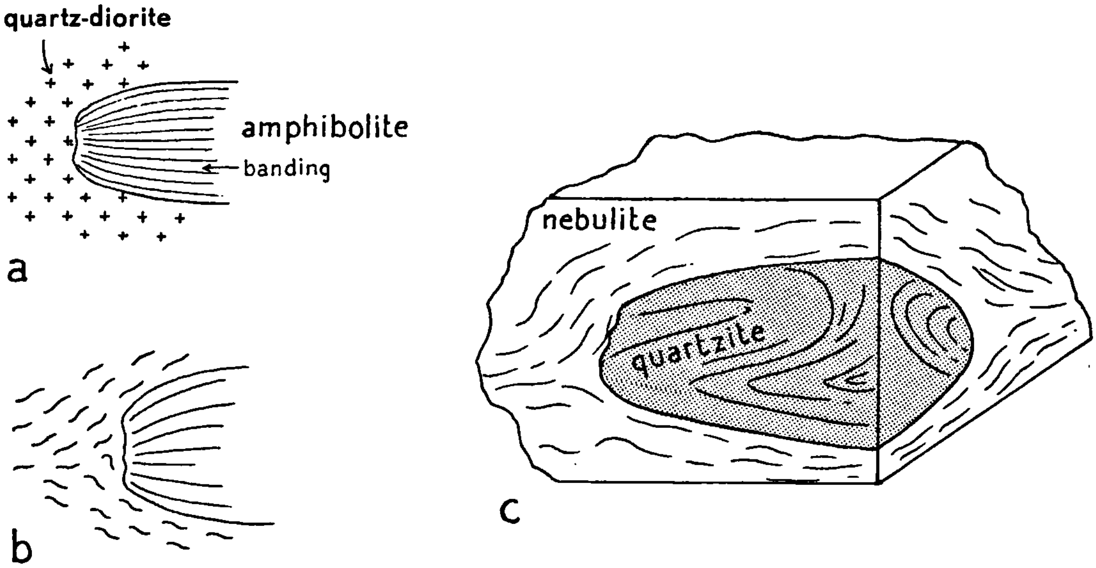


Fig. 27. Relics of boudinage structure in rheomorphic quartz-diorite.

a very irregular shape. The sizes of the folded inclusions are very variable. In general only parts of folds have been found. East of lake Artax for example there are several big inclusions of fold hinges.

Relics of boudinage structure occur in different localities. In these instances features such as are illustrated in fig. 27 can be seen. In most cases only one or part of one boudin is present; the other originally associated boudins have not been found. Undoubtedly this is due to flow in the enclosing rocks.

Unconformable granitic veinlets showing ptygmatic folding are of frequent occurrence in inclusions of amphibolite or biotite-bytownite-gneisses. It is striking that these never show such severe folding as ptygmatic veins occurring in the mica-schists or sillimanite-gneisses (see fig. 40). Possibly this is an expression of the greater competency and lower plasticity of the amphibolites as compared with the gneisses and schists.

Several strongly folded bodies of pegmatite have been encountered in quartz-diorite, for instance, east of the lake Artax.

Along the road immediately west of Lapège and opposite the lunch tree, segregation pegmatites are common in fold hinges of isoclinally folded amphibolites or lime-silicate rocks. In the latter locality these saddle reefs are still connected with several of the numerous parallel bands of pegmatite in the quartz-diorite.

It will be clear that many synkinematic structures have been preserved in the quartz-diorites. However, in several cases the original relations, have been lost as a result of the flow in the rock series, for instance between the boudins of boudinaged bands of amphibolite.

K. PARALLEL VEINS AND BANDS OF PEGMATITE AND LEUCOCRATIC GRANITIC ROCKS

Parallel bands of pegmatite and leucocratic granitic rocks have been encountered in many places.

In important outcrops at about 600 m south of the Pic de Pioulou, in the east slope of the Pic de Bassibié, along the track between the lake Artax and the Col de Lastris (about 500 m north of the Pic de Querquéou) the leucocratic bodies predominate compared with the enclosing quartz-diorites. Elsewhere, for instance near point 1555 and opposite the lunch tree, they are less abundant, but still of frequent occurrence.

The contacts of the leucocratic bands with the enclosing rocks are usually sharp (transition zones not wider than 5 cm). The discontinuous biotite schlieren in the quartz-diorite are in general parallel to the contacts of the pegmatites and granites (see fig. 28).

The thickness of the bodies varies between a few centimetres up to 10 m or more. In the localities, where the bands predominate there are often thin layers of quartz-diorite which can be followed for many tens of metres between the leucocratic bands. In these layers small inclusions of amphibolite or biotite-bytownite-gneiss have been found, which have been rotated by the flow movements in the rock series. Locally those small bodies are partly or completely incorporated in the leucocratic rock. In many cases the rotated inclusions have pushed away the surrounding leucocratic veins (see fig. 18). Cross cutting contacts between inclusions and the pegmatite and granite do not occur. These observations indicate that the flow has taken place after the emplacement of the leucocratic rocks.

In several cases the veins are still connected with bodies of pegmatite or granite of which it is possible to prove that they are synkinematic. Near point 1555, for instance, an inclusion of biotite-hornblende-gneiss (see p. 172) occurs, which is penetrated by leucocratic quartz-diorite. The melanocratic gneiss, together with the leucocratic rock is strongly folded (see fig. 29), Linear texture is evident in the gneiss. Microscopical investigations show that there is no trace of disorientation of biotite and hornblende along the contacts of the veins. Based on these observations it is concluded that this vein is synkinematic. Two leucocratic bands in the quartz-diorites are still connected with the veins in the inclusion. Probably these bands are likewise synkinematic. The relations of both rock bodies to the enclosing quartz-diorites

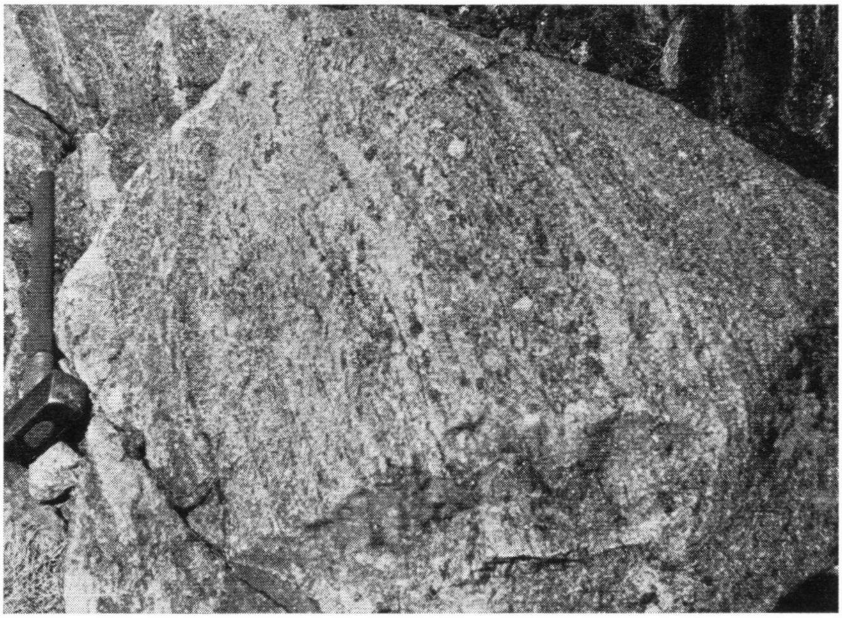


Fig. 28. Parallel bands of leucocratic rock in quartz-diorite (east slope of the Pic de Bassibié).

Fig. 29. Folded biotite-hornblende-gneiss, penetrated by veins of leucocratic quartz-diorite (point 1555).

are similar with those of the other leucocratic zones, which are of frequent occurrence in this locality.

Opposite the lunch tree similar features have been observed. Several of the parallel pegmatite veins occurring in the quartz-diorite are still connected with synkinematic saddle reefs (see fig. 30), present in the fold hinges of several isoclinally folded bands of amphibolite or biotite-diorite-gneiss (see p. 181). Therefore it is concluded that some of the leucocratic bands in the quartz-diorites have been formed during the synkinematic phase.

The distribution of the parallel bodies of pegmatite and leucocratic granite in the quartz-diorites is similar to that of the sills of pegmatite and granite in the sillimanite- or biotite-gneisses. The width of the sills likewise varies between a few centimetres and more than 10 m. In many places these rock bodies predominate over the enclosing gneisses, elsewhere they are less abundant but in most cases still fairly frequent.

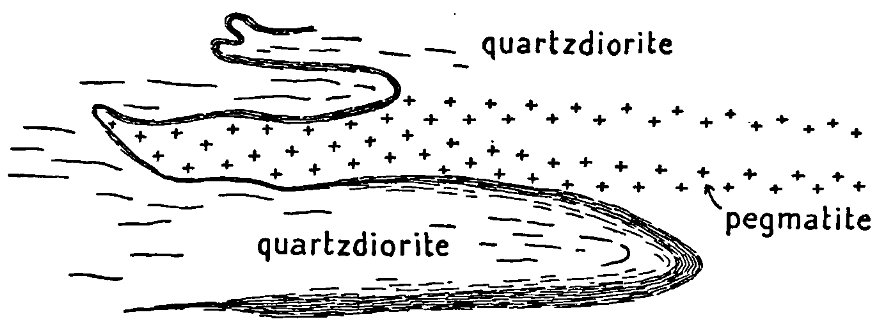


Fig. 30. Saddle reef of pegmatite which is still connected with parallel pegmatite bands in the quartz-diorite. Scale 1: 50. (lunch tree).

L. ORIGIN AND AGE

It is concluded that the quartz-diorites of the Trois Seigneurs massif have to a large extent been produced as a result of rheomorphism at the expense of pre-existing sillimanite-gneisses. The following arguments are quoted in support of this conclusion.

1) In the quartz-diorites, inclusions of marble, amphibolite, quartzite, etc. (see Chapter IV) are usually of frequent occurrence, whereas inclusions of original pelitic rocks (sillimanite-gneiss) are relatively very rare.

2) Numerous parallel bands of pegmatite and other leucocratic rocks, occur in the quartz-diorites. Some of these are undoubtedly synkinematic. Their original position has been well preserved during the flow movements and their distribution has remained the same as in the gneisses, in which rheomorphism did not take place. The leucocratic bands have not been broken as were the layers of amphibolite and marble but apparently reacted as plastic masses in the flowing quartz-diorites.

3) In several localities it was possible to distinguish various stages in the formation of quartz-diorite at the expense of sillimanite-gneisses as a result of flow and static recrystallization.

4) Sillimanite and cordierite occur in the whole area where quartz-diorites are exposed. These minerals have not only been found near the contacts with

bodies of sillimanite-gneiss, but also elsewhere far from any occurrence of these gneisses.

It will be clear that countless relics of the pre-existing rock series are still present in the quartz-diorites.

The field observations showed that quartz-diorites in which flow structures could be demonstrated, greatly predominate over other rock types in the eastern part of the Trois Seigneurs massif. This implies that rheomorphism has taken place on a regional scale in this area. It seems that this is an exception in the Pyrenees. In the St. Barthélemy massif for instance (ZWART, 1954, 1958) quartz-diorites occur as unconformable bodies of varying dimensions in the sillimanite-gneisses. The gneisses predominate in this area. Flow structures have been observed in the quartz-diorites. It was possible to establish that the masses of this rock type never show traces of pushing aside of the enclosing rocks. The influence of rheomorphism has only been local in the last massif. Only in a few places has the cohesion of the sillimanite-gneisses been lost, which resulted in flow and homogenization of the mobilized material.

In the Trois Seigneurs massif the quartz-diorites never break through the sillimanite-gneiss zone which occurs as a continuous envelope above these rocks. Therefore it is probable that they are still more or less autochthonous.

In the author's opinion the quartz-diorites cannot be regarded as magmatic rocks. There are flow structures, but on the other hand a comparison with the biotite-granodiorite of the Pic des Trois Seigneurs, which is of igneous origin reveals important differences. 1) The granodiorite has a typical hypidiomorphic structure, the quartz-diorites are in general granoblastic. 2) In the outcrop and in the hand-specimen the former rock type is always homogeneous, this is in complete contrast to the quartz-diorites, which contain numerous relics of the pre-existing rock series. 3) The plagioclases of the granodiorite often show a distinct oscillatory zoning, whilst those of the quartz-diorites hardly ever do. 4) The relations with respect to the enclosing rocks of the bodies of either rock type are very different (see also Chapter VIII).

Many synkinematic structures or relics thereof have been preserved in the quartz-diorites. It has been demonstrated that this rock type has been formed at the expense of pre-existing biotite-gneisses and sillimanite-gneisses. Inclusions or larger bodies of these gneisses may be enclosed by the quartz-diorites. These facts indicate that the quartz-diorites have been formed during the post-kinematic phase. This is also evidenced by the total absence of crystallization foliation (MISCH, 1949, p. 692) and a linear texture in this rock type.

CHAPTER IV

RESISTERS *)

This chapter consists of three parts. In part one those rock types will be discussed, which are of sedimentary origin, whereas in part two the types which are probably of igneous or volcanic origin, will be dealt with. The quartz-gabbros, will be described in part three. Their properties differ in many respects from all the other resisters.

In synkinematic gneisses, the resisters always occur as conformable bands or lenticular bodies, which can be followed over considerable distances.

In quartz-diorite the marbles, amphibolites, etc. as a rule do not form continuous beds but they are met with as inclusions of variable dimensions. It could be proved that the layers of these rocks have been broken into pieces as a result of rheomorphism. The mutual relations of the inclusions have been extensively treated in Chapter III.

In table V a review is given of all the types of resisters which have been found in the Trois Seigneurs massif.

PART I. ROCKS OF SEDIMENTARY ORIGIN

A. MARBLES AND ASSOCIATED LIME-SILICATE ROCKS

Marbles are fairly common in the vicinity of Lapège and of the lake of Artax, as has already been mentioned by THIEBAUT (1956, p. 60—61). Elsewhere in the mapped area they are also often present, although less frequent.

In the field the marbles can often be recognized from a great distance. They are mostly of a light grey colour and have rounded forms. Banding can be conspicuous by lime-silicate bands standing out through weathering. Sometimes marbles stick out in unexposed regions as elongated knobs of rock, for instance near point 1555 east of the lake Artax and near point 1254 between Illier and Lapège.

Magnesian and non-magnesian marbles can be distinguished. These types may be intercalated with one another. Biotite-gneisses and hornblende-gneisses are in several cases closely associated with marbles, e. g. near Lapège, although they usually appear independently.

I. Non-magnesian marbles and associated lime-silicate rocks

a. Pure marbles

White coloured pure marbles have been found 600 m west of Carnies and 1,300 m south of the lake of Artax. J. THIEBAUT (1956, p. 60) mentions the occurrence of a white marble near Mercus west of Lapège. Elsewhere the marbles are always impure.

*) This term is used, as defined by H. H. READ in his book "The granite controversy".

b. Lime-silicate bands in the marbles

Bands of lime-silicate rock are of frequent occurrence in the marbles. As a rule they have a thickness of several centimetres. South of Hioula a band of lime-silicate rock occurs independently in sillimanite-gneisses.

1. *Diopside-bytownite-gneiss*

This rock type is generally finely banded. Light green more or less continuous streaks, rich in diopside, alternate regularly with light grey felspathic bands.

Microscopy. In the felspar-rich bands a typical mosaic is seen, consisting of simply-shaped individuals of b y t o w n i t e. The grain size varies between 1 and 3 mm in the respective bands. Each individual is twinned. Occasionally the plagioclase is partly altered into sericite, muscovite, albite, clinozoisite and calcite.

D i o p s i d e with $n\gamma/c$ appr. 39° and 2 V appr. + 60 is colourless and shows diallage cleavage. In many cases the clinopyroxene is well-oriented and subhedral. The prisms are up to 3 mm in length.

T r e m o l i t e is of frequent occurrence and builds irregular crystals or idioblastic prisms replacing the clinopyroxene.

Accessories are q u a r t z, brown pleochroic t i t a n i t e, a p a t i t e and p y r i t e. The latter appears either as small branching grains in association with clinozoisite in felspar, or independently in clusters of euhedral crystals.

2. *Diopside-clinozoisite-prehnite rock*

About 100 m south of Hioula a band, 1 m in thickness and some tens of metres in length, consisting of diopside-clinozoisite-prehnite rock occurs independently in sillimanite-gneiss. In hand-specimen this granular rock has a yellowish grey colour. Thin parallel veinlets or lenses of quartz are frequent.

In thin section q u a r t z is plentiful and forms either parallel veinlets and lenses or trails of elongated and oriented grains.

Elongated crystals of d i o p s i d e, with a size of at most 2 mm, are regularly distributed in clinozoisite or prehnite. The diopside is in many cases replaced by prehnite and occasionally by clinozoisite.

G a r n e t occurs in several narrow zones in the rock and is sieved with oriented grains and lenses of quartz. Small irregularly shaped relics of the mineral have also been found sparsely distributed in clinozoisite. It is probable that the garnet has been replaced by clinozoisite.

Small remnants of b a s i c p l a g i o c l a s e and masses of sericite are of local occurrence in prehnite.

C l i n o z o i s i t e is in certain parts of the rock the most important constituent next to quartz and forms an aggregate in which oriented lenses, streaks and grains of quartz occur (see under garnet). The grain size of the clinozoisite is up to 2 mm; in most cases the individuals are elongated, but irregular in shape and randomly oriented.

In other places p r e h n i t e instead of clinozoisite forms an aggregate of irregular plates with a size of 1 to 5 mm. In these parts the prehnite shows exactly the same relations with regard to quartz and the other constituents as clinozoisite in the clinozoisite-rich parts of the rock. Relics of the latter mineral occur frequently. The clinozoisite has been replaced by prehnite. Many stages of replacement have been observed.

In this rock a primary mineral association of garnet, diopside, basic plagioclase and quartz occurs. During a later stage of the metamorphism clinozoisite has replaced garnet and probably also plagioclase. Prehnite is still later and has replaced plagioclase and nearly all clinozoisite in certain places.

3. *Diopside-hornblende-clinozoisite rock*

At the extreme SE point of the lake Artax a small marble inclusion has been encountered in nebulitic quartz-diorite. In hand-specimen numerous flat and well-oriented lenses of lime-silicate rock can be seen in the light grey to light medium grey mass of calcite. Quartz grains, with a length of 1 to 2 mm are regularly distributed in the marble.

Microscopy. Separate euhedral prisms of hornblende, irregular grains of clinozoisite and elongated crystals of quartz occur in the medium-grained mosaic of calcite.

The lime-silicate lenses consist for the greater part of clinozoisite, diopside, pale green amphibole and a little quartz. Diopside and amphibole are intimately intergrown. In the clinozoisite, which is undoubtedly of secondary origin, no relics have been found of the mineral which it has replaced. It is possible that diopside, together with another mineral (basic plagioclase or grossularite), formed the original paragenesis and that the pale green hornblende and clinozoisite have originated much later in the metamorphic history.

In the lime-silicate rocks just-described, alteration products of the primary minerals are much more abundant than in other types of resisters which are rich in hornblende or in biotite. Presumably the former types are more sensitive to retrograde metamorphic processes than the latter (see also p. 167 and p. 175).

c. Marbles and lime-silicates near Lapège

1. *Field relations*

In garnet-bearing biotite-gneisses (see p. 131) or in quartz-diorites immediately south and also ESE of Lapège, marbles and lime-silicates occur in close association with each other. Banding is very pronounced in these rocks. The marble layers alternate regularly with layers of hornblende-gneiss and fine-grained biotite-gneiss. Each of the three components varies greatly in thickness, the lime-silicate band never reach a thickness of more than one metre. The marble layers can be much thicker, but may also have a thickness of only 1 or 2 mm. The banding appears to be of sedimentary origin. The influence of metamorphic differentiation was apparently small.

In the outskirts of a limestone quarry along the road from Niaux to Lapège, 600 m ESE of the last village the rocks are isoclinally folded, the axial planes are very steep and dip to the east, the fold axes are striking SE—NW. Under Lapège the strata are almost horizontal. There the marble series attains a thickness of more than 50 m, and is apparently not folded. The lime-silicate bands in the marble frequently show a well-developed boudinage structure. Between the boudins quartz segregations are of frequent occurrence. In many cases the boudins have been drawn apart over a distance of more than one metre. Conformable quartz lenses occur in the marble- and in the lime-silicate bands. In both rock types these lenses are also boudinaged. The quartz boudins are always joined together.

Along the road, immediately west of the village, rather thin isoclinally folded lime-silicate bands have been observed, lying horizontally in quartz-diorite or migmatitic gneiss. The trends of the fold axes are very variable in this vicinity.

In the limestone quarry many conformable pegmatites occur. Their thickness varies from 1 cm to more than half a metre. The contacts with the enclosing rocks are usually transitional. The sills are in general fairly continuous and can be followed over distances of several tens of metres. They show a distinct preference for occurring in the bands of fine-grained biotite-gneiss. The bands of this rock type do not behave as reaction zones along the contacts of the pegmatites. The separate biotite-gneiss layers have usually a constant thickness, whereas the enclosed pegmatites show a variable thickness. Locally such sills may be just as thick as the enclosing band. Where they become thinner, the fine-grained gneiss reappears. Where they wedge out, the biotite-gneiss replaces the pegmatite. Relics of biotite-gneiss, apparently not disoriented, have sometimes been found in the pegmatites. Occasionally continuous pegmatites occur between marble bands. In and along the contacts of these sills no relics of the fine-grained biotite-gneiss have been observed.

It should be concluded that the pegmatization had a selective effect. The conclusion that we are concerned with a case of "une granitisation progressive d'une roche calcaire" (THIEBAUT, 1956, p. 61) is not justified.

Cross-cutting pegmatites are also present. Their relations with respect to conformable pegmatites could not be determined.

2. *Pink biotite-marble*

This type does not occur very frequently, but is very conspicuous in the field. The bands have a thickness of at most half a metre. A regular alternation of coarser bands with a grain size of 3 to 5 mm and finer grained zones can often be seen. Greenish black specks of unoriented biotite are evenly distributed. They are most frequent in the finer grained bands.

Microscopy. In the coarser bands, plates of greyish olive biotite, irregular crystals of plagioclase (andesine), small round quartz grains and some ore occur sparsely distributed in an aggregate of calcite. The individuals of calcite have somewhat interlocking contacts, they are sometimes elongated and then show parallel arrangement.

In the finer grained bands biotite, plagioclase and quartz are more strongly represented. The crystals of these constituents form a more or less continuous net-work in the aggregate of calcite. Muscovite replacing plagioclase and biotite is sometimes present. Titanite, pale yellow epidote (always in biotite) and pyrite are accessories.

3. *Hornblende-bearing marble*

These light to medium grey coloured rocks constitute the most common type. Banding is distinct: lighter coloured bands with a few parallel streaks or oriented crystals of hornblende alternate with darker coloured bands in which this mineral is much more prominent. In many cases yellow greenish specks of epidote occur evenly distributed in the rock.

Microscopy. Shapeless quartz grains (0.3—0.6 mm), very irregular crystals of plagioclase (An 46, size 1—1½ mm) and strongly embayed prisms of blue green hornblende lie separately in an aggregate of calcite. Occasionally the hornblende is partly altered into a pale green actinolite. The microscopical relations of epidote are given on p. 158.

4. *Fine-grained biotite-gneiss*

This rock type shows a medium grey colour often with a violet tinge. The thickness of the bands varies between a few decimetres and a fraction of a millimetre. Conformable and discontinuous segregation veinlets, a few millimetres thick occur frequently. They are composed of quartz and felspar.

In thin sections an aggregate is visible of elongated grains of plagioclase (An 38) and quartz often showing parallel arrangement. Biotite occurs in considerable amounts regularly distributed as separate and irregular small plates. Its cleavage is always oriented. The largest dimensions of the mica crystals often do not lie in the direction of the foliation. The average grain size of the constituents varies between 0.2 and 0.4 mm in a direction perpendicular to the banding. Quartz often predominates over plagioclase.

As accessories microcline (interstitial to quartz and plagioclase), apatite, zircon, orthite, titanite and ilmenite occur.

The medium-grained segregation veinlets consist of quartz and euhedral plagioclase (oligoclase-andesine). The plagioclase prisms do not show preferred orientation. Antiperthite has been frequently observed. Along the contacts of the lenses the mica crystals of the enclosing gneiss are somewhat coarser than usual and randomly oriented.

5. *Hornblende-gneiss*

Medium grey layers of fine- to medium-grained hornblende-gneiss are of frequent occurrence. In hand-specimen hornblende is visible, occurring either as separate crystals or in parallel and discontinuous streaks. Light greenish yellow streaks of epidote are often present.

Under the microscope banding is seen to be produced by variations in the relative amounts of the different constituents. Narrow bands consisting of plagioclase and hornblende alternate with thicker bands composed of plagioclase, hornblende and a varying amount of quartz and calcite. In many cases the latter mineral is absent. In some cases quartz predominates over the other minerals. The crystals often show an approach to parallel arrangement. In the plagioclase-hornblende bands, the felspar crystals are always strongly elongated parallel to the banding. Small relics of a pale green clinopyroxene occur rarely in the hornblende.

In the vicinity of the limestone quarry the hornblende usually has a pleochroism of n_γ = moderate blue green to greyish blue green, n_β = dark yellowish green, n_α = light to pale olive. On occasion the crystals of this mineral show a distinct linear arrangement (their c-axes lie parallel), but often they are randomly oriented. In many cases the blue green hornblende is partly or almost entirely altered into pale green actinolite, which is always sieved with fine quartz pellets

6. *Microclinization*

The microscopical investigations of the rocks of the marble series of Lapège showed that the influence of microclinization has been important in many cases. Its effect is most pronounced in the fine-grained biotite-gneiss bands, but less obvious in quartz-rich hornblende-gneiss. In the other components of the lime-silicate series microcline occurs rarely.

In the biotite-gneiss bands microcline with a well developed cross-hatched structure has replaced plagioclase and quartz. The mineral occurs usually as long-drawn and oriented grains of 0.2 mm length. Occasionally small elongated porphyroblasts were seen which are sieved by plagioclase and quartz. Biotite is present in quantities equal to those in the not microclinized bands. Its orientation remains always distinct. Plagioclase (An 32) is equidimensional or elongated and oriented. Its grain boundaries are always irregular. Thin rims of clear albite were often seen in contact with microcline.

The effect of microclinization is less pronounced in quartz-rich hornblende-gneiss. The grain size of these microclinized bands varies strongly and at first sight through the microscope they seem to be strongly cataclastic. The crystals have however, hardly any wavy extinction. It appears that microcline has penetrated the plagioclase and quartz along the cleavages and cracks, in such a way that the individuals of these two minerals seem to have been broken up into much smaller crystals. Microcline, showing cross-hatched structure, forms small irregular grains of varying dimensions (0.1 to 0.4 mm). Small relics of plagioclase occur frequently in the potash-felspar. Biotite is present in small amounts. Intimate intergrowths with hornblende have been observed. Possibly the mica has replaced the hornblende.

7. *Epidotization*

Epidote is often present in the rocks in the vicinity of the limestone quarry. The relations and occurrence of this mineral are somewhat different in the various rock components. After the examination of about 20 thin sections the following rules can be given.

1) In bands in which biotite and microcline are present, epidote has been found as branching individuals in plagioclase or as idioblastic crystals in biotite.

2) The megascopically visible streaks of epidote occur exclusively in the hornblende-plagioclase bands of the hornblende-gneisses. This mineral is always abundant in these bands and presents itself as irregular grains replacing plagioclase and hornblende. In the latter mineral the epidote is regularly sieved by small vermicules of quartz.

3) In bands with calcite (and also in marbles) epidote is always finely sieved by vermicular quartz and forms reaction rims between plagioclase and calcite and likewise between plagioclase and hornblende. Epidote appears less frequently in such bands as irregular grains in plagioclase and hornblende. Clinozoisite forms reaction rims between plagioclase and calcite. In other cases epidote is present. Clinozoisite rims between microcline and calcite were rarely found in epidote-bearing marbles.

In association with epidote or clinozoisite plagioclase is usually sericitized. Elsewhere the crystals of this felspar are as a rule completely fresh.

In many cases it has been observed that in parts of the rock series where epidote has replaced blue green hornblende on a large scale, actinolitization has had no or little influence. Furthermore alteration of hornblende into actinolite is frequently seen in places where epidote is absent.

8. *Concluding remarks*

The most conspicuous features of this rock series are microclinization, epidotization and the presence of relatively sodium-rich plagioclase.

The microclinization has probably taken place during an early stage of the Hercynian metamorphism and perhaps even during the synkinematic phase. The most important argument in favour of this conclusion is that in the bands where the microcline is most strongly represented, the biotite is very well oriented and the parallel arrangement of the elongated quartz and felspar crystals is also very distinct. Potash metasomatism under static conditions should have had resulted, among other things, in disorientation of biotite.

Yet it must be assumed that the microclinization has taken place during an advanced stage of the synkinematic phase. It could often be established that the microcline has replaced earlier plagioclase and quartz.

As a rule bytownite or anorthite occur in other types of resisters of sedimentary origin (hornblende- and biotite-bytownite-gneisses) with the same mineralogical composition as the rocks from the lime-silicate series of Lapège. Anorthite is also present in the magnesian marbles south of Lapège. Andesine, sometimes oligoclase, but very rarely basic relics of labradorite have been encountered in the lime-silicate series of Lapège. Basic plagioclase is even absent in parts of this rock series where microclinization and epidotization have had no influence. It is therefore possible that the activity of alkali metasomatism during the synkinematic phase has generally prevented the development of basic plagioclase.

Another cause of the origin of acid plagioclase is undoubtedly the epidotization, which process has also attacked a part of the plagioclase.

It is probable that the epidote is post-kinematic since this mineral usually does not show preferred orientation and likewise it replaces in many cases unoriented hornblende crystals.

The repartition of epidote and actinolite suggests that these constituents are not contemporaneous. Possibly the latter mineral is associated with the late unconformable pegmatites (see below), whereas epidote is somewhat earlier. The cause of the epidotization could not yet be determined.

II. Magnesian marbles and lime-silicate rocks

Lacroix (1910, tome IV, p. 302, 707) has already mentioned the occurrence of a humite-bearing marble immediately west of the small hamlet of Carniès. This marble, with occasional bands of lime-silicates, can be followed over at least 100 m. In three other localities of the mapped area, Mg-bearing marbles, at times associated with magnesian lime-silicates, have been found.

a. Humite-clinochlore marble

In nebulitic quartzdiorite more than 1,300 m SE of the cabin of Artax a marble inclusion occurs with a length of 30 m and a thickness of about 5 m, which strikes east—west and dips to the north. In this inclusion bands of a few decimetres thickness of pure white marble alternate with equally thick bands of humite-clinochlore-marble. In hand-specimen the humite-clinochlore marble has a moderate yellow green to pale yellowish green colour. On polished surfaces many green specks can be seen in the light grey coloured ground-mass. These specks occupy 30 to 40 % of the volume. They are not evenly distributed, but banding is not clear. Occasionally small brownish black spots lie in the green specks, but as far as it is visible megascopically they can also occur independently. Unoriented plates of clinochlore are sparsely distributed.

Microscopy. C a l c i t e with an average grain size of 0.8 mm forms a granoblastic mosaic of grains with strongly interlocking contacts. Masses consisting of s e r p e n t i n e and b r u c i t e *), averaging 1 mm in size, occur evenly distributed or sometimes in clusters. The serpentine pseudomorphs are always subhedral. "Maschenstruktur" (CHUDOBA, 1932, p. 121) is still conspicuous. Occasionally relics of a h u m i t e mineral are present in the serpentine. They are always associated with concentrations of o r e, appearing as small parallel needles or as small irregular grains. Such concentrations seldom occur independently in serpentine. The humite mineral is distinctly pleochroic with n_γ = greyish yellow, n_β = colourless and n_α = pale yellowish orange ($n_\beta < n_\gamma < n_\alpha$). Small crystals of a colourless mineral resembling f o r s t e r i t e occur rarely in the groundmass of dolomite or calcite. C l i n o c h l o r e forms irregularly shaped plates with dimensions of at most 3 mm. These plates may envelope several serpentine masses and apparently partly replace them. It is however, more probable that the clinohumite has been replaced by clinochlore and that the serpentine is later than the clinochlore.

As an accessory apatite occurs as oval-shaped grains of 0.2 mm size at most.

b. Phlogopite-bearing forsterite marble

A phlogopite-bearing marble has been found at about 220 m north of the church of the village of Orus. In this rock numerous dark greenish grey specks can be seen in the light grey groundmass of calcite. Thin streaks of phlogopite are frequent.

Under the microscope this rock is similar to the type just described. The s e r p e n t i n e masses are mostly entirely, but in several cases partly replaced by a fine-grained aggregate of calcite. The subhedral shape of these pseudomorphs is less conspicuous than in the marble just-described. Several times it has been observed that the fine calcite grains lie in the serpentine. As a rule this is not apparent because the calcite grains are too densely packed. The original "Maschenstruktur" is often still visible in

*) A. LACROIX (1901—1909, tome III, p. 402) already described brucite, occurring as an alteration product of humite and spinel in lime-silicate bands in marbles near Arignac, south of Foix (Massif de l'Arize).

the calcite masses. Small xenoblastic grains (at most 0.3 mm across) of f o r s t e r i t e are rare; they are sometimes altered into clinochlore.

P h l o g o p i t e occurs in more or less discontinuous streaks. Its pleochroism is $n_\gamma = n_\beta =$ greyish orange, $n_\alpha =$ nearly colourless. In some streaks the phlogopite is fine-grained, lath-shaped and well-oriented; in others the mica crystals are coarser, more irregularly-shaped and often randomly oriented.

C l i n o c h l o r e is much more skeletal in this marble than in the one described above.

As an accessory s p i n e l appears as pale green (10 G 6/2) subhedral or euhedral grains of at most 0.2 mm in diameter.

c. Magnesian marble and lime-silicate rock south of Lapège

1. *Marble*

Along the road Niaux-Lapège immediately west of the hairpin lying closely SE of Lapège, a marble layer with lime-silicate bands of several metres thickness occurs in nebulitic gneisses. This layer can be followed over a distance of 150 m in east—west direction. The dip and strike of the strata vary; locally the rocks are strongly folded. In the medium light grey

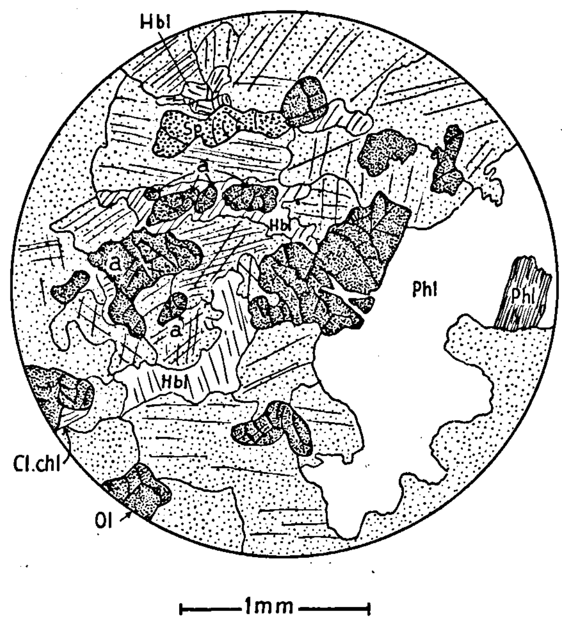


Fig. 31. Magnesian marble.
Cl.chl = clinochlore, Hbl = pargasite, Ol = forsterite, Phl = phlogopite, Sp = spinel.
The islets of forsterite, indicated with an a, show optic continuity

marble layers phlogopite-rich bands (at most 1 cm wide) are of frequent occurrence. Along the boundaries of these bands the marble is coarser grained than elsewhere and has a white colour.

Microscopy. A large number of irregularly-shaped crystals of other minerals has been found in a fine- to medium-grained mosaic of faintly interlocking c a l c i t e (see fig. 31).

F o r s t e r i t e, averaging 0.6 mm in size, occurs evenly distributed. Sometimes the grains are elongated and show a tendency to parallel arrangement. Occasionally this mineral is intimately intergrown with clinopyroxene. In several cases the forsterite has been partly altered into clinochlore and also into serpentine.

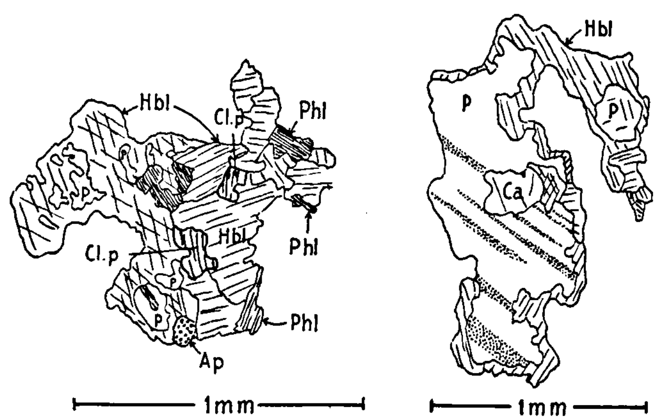
C l i n o h u m i t e is present in small amounts and forms either separate crystals with the same shape as forsterite or smaller or larger patches along grain boundaries in the olivine crystals. The clinohumite has replaced the forsterite.

C l i n o p y r o x e n e occurs on one hand evenly distributed as small irregular or subhedral individuals, averaging 0.5 mm in size, and on the other hand in trails of elongated and oriented crystals of at most 5 mm in length and 2 mm in width. Uralitization has frequently been observed.

A n o r t h i t e builds strongly embayed and often skeletal grains with a maximum size of 1 mm, but also forms discontinuous trails of small and equidimensional individuals in clinopyroxene.

S p i n e l has euhedral or very irregular shapes. The mineral is in many cases enveloped by rims of pargasite. As a rule clinochlore has penetrated between the contacts of these two constituents. Along fracture planes the spinel is altered into a mineral with a high birefringence, resembling sericite. After X-ray analysis it was determined by H. J. STRUWE (1958) as diaspore.

P a r g a s i t e has a pale grey colour, 2 V appr. + 70° and n_γ/c appr. 25°. It occurs as separate crystals and also forms irregularly shaped aggregates (see fig. 32). The amphibole generally forms rims around clino-



b a

Fig. 32. a) Plagioclase crystal partly enveloped by a rim of pargasite.
b) Part of a pargasite aggregate in magnesian marble.
Ap = apatite, Cl. p = clinopyroxene, Hbl = pargasite, Phl = phlogopite.

pyroxene and anorthite and somewhat less frequently around forsterite and spinel. The crystals of this mineral are usually skeletal. One part of such a crystal may enclose smaller or larger relics of e. g. plagioclase and another part clinopyroxene or forsterite. This is also the case with the pargasite aggregates. It seems reasonable to conclude that the pargasite has replaced the four other minerals. The amphibole should not be regarded as an alteration product of only one of the earlier constituents, but probably it has used from each of the four the material that was needed for its formation.

The phlogopite-rich bands consist of a number of parallel streaks (at most 1 mm thick), which are built up of rather small and often randomly oriented plates of about 0.3 mm in size. Irregularly shaped aggregates of the mica are of frequent occurrence near these bands in calcite. Elsewhere in the rock the phlogopite may form irregular plates of varying sizes replacing forsterite or pargasite (see fig. 31).

Accessories are apatite, titanite (in clinopyroxene) and pyrite. Apatite is especially frequent in the phlogopite-rich bands.

2. *Lime-silicate bands*

The marble layers alternate regularly with dark grey to brownish grey silicate bands. In these bands plates of unoriented clinochlore, which can attain a size of 2 cm, are conspicuous. Phlogopite is present in discontinuous streaks, in irregularly shaped vein-like masses and as separate small plates, which occur more or less evenly distributed. Amphibole predominates in most cases over the other constituents. The crystals of this mineral often show a fan-shaped arrangement. Olivine and spinel occur as flat and well oriented crystals in the amphibole. In some parts of the rock very thin continuous trails of regularly alternating olivine and spinel can be seen.

On a microscopical scale foliation is evident in this rock. This becomes clear by the distribution and the pronounced orientation of forsterite and spinel.

Forsterite occurs rather evenly distributed and forms continuous trails (at most 1 mm wide) of elongated and well-oriented crystals. The crystals can attain a length of 1 cm. Often they are shorter and divided into separate islets by replacing amphibole or clinochlore. The c-axis of the olivine is nearly always in the direction of the foliation.

Spinel has a pale green colour and occurs, like forsterite, evenly distributed in trails of elongated and oriented grains. Their dimensions vary; trails of stout individuals with a size of e.g. 2 × 1 mm but also of 2.5 × 0.3 mm may be present. Occasionally parallel trails (at most 2 mm thick) of spinel and forsterite grains alternate regularly. Along fracture planes spinel has been partly altered into diaspore (STRUWE, 1958).

Pargasite has a pale grey colour, 2 V appr. + 70°, n_γ/c appr. 25°. Usually this mineral occupies most of the space between the olivine and spinel trails. The amphibole does not show orientation and usually forms a packed aggregate of crystals in fan-shaped arrangement. In many cases pargasite penetrates between the planes of intergrowth of spinel and forsterite and replaces partly one or both minerals. The amphibole shows also a tendency to penetrate along the fracture planes of the two earlier constituents separating the individuals into isolated islets.

Phlogopite is present in discontinuous streaks in parts of the rock where pargasite predominates, forming an aggregate of small and irregular plates which are locally well-oriented. Elsewhere this mica occurs sparsely distributed as skeletal crystals of at most 0.6 mm in size, replacing the amphibole. In other parts of the rock where clinochlore is abundantly represented the phlogopite builds large shapeless plates with a size of 8 mm at most. Their contacts with the clinochlore are almost without exception sharp. Occasionally the cleavages of the mica individuals continue without interruption into the adjoining clinochlore. In many cases the cleavages of the mica crystals lie oblique to those of the chlorite plates The relations between the two minerals suggest that clinochlore is not an alteration product of phlogopite.

Clinochlore often shows polysynthetic twinning according to the mica law. It attains always relatively large dimensions. In certain lenticular patches the clinochlore predominates over the other constituents. There the grains of spinel and forsterite are often divided into separate islets. Small relics of pargasite occur in great quantities. Clinochlore has largely replaced the pargasite and perhaps also part of the forsterite and spinel. Elsewhere the mineral builds large and skeletal plates of several millimetres in size, apparently replacing the three main constituents. In these places the clinochlore shows a pronounced tendency to penetrate the planes of intergrowth between forsterite and spinel.

It is difficult to decide at the expense of which mineral the clinochlore has originated. It seems clear that in the clinochlore-rich patches pargasite has to a large extent been replaced. The preference shown by the clinochlore for isolating spinel and forsterite from one another could suggest that in many cases the chlorite has replaced these two constituents. This is however, not very probable. Pargasite shows in fact the same relations with respect to spinel and forsterite and it is more likely that the chlorite as a rule has replaced the pargasite which was found already between the grain boundaries of the two minerals.

Hydrothermal replacement veinlets may traverse the rock. In clinochlore or forsterite they are filled with ore, in olivine with calcite, in forsterite or pargasite with phlogopite and in spinel and pargasite with clinochlore.

Occasionally forsterite has been replaced by a light yellow and untwinned humite mineral. After X-ray analysis Struwe (1958) has determined it as clinohumite. This mineral occurs as narrow seams along fracture planes of the olivine, but also larger portions of the forsterite grains may be replaced. Sometimes complete pseudomorphs have been observed. Such crystals of clinohumite always make part of the forsterite trails, and therefore it is not possible to determine whether the pargasite is contemporaneous with or later than the former mineral.

Tourmaline. As an accessory an optically negative unaxial mineral occurs with a pleochroism n_0 = pale- yellow and n_ε = colourless. Its birefringence is moderate, but its refractive index is distinctly lower than that of olivine. The crystals have a size of 1 mm at most and are usually equidimensional. Sometimes they are subhedral and rectangular. Prismatic crystals have not been found. Fracture planes may have the same shape as those of forsterite. Probably this mineral is a Mg-bearing tourmaline (dravite).

Apatite is more common in the phlogopite-rich parts of the rock than elsewhere.

3. *Conclusions*

The repartition of olivine and spinel might be regarded as a kind of segregational banding. It is probable that this banding and especially the pronounced orientation of forsterite has originated as a result of the Hercynian deformation. Possibly the anorthite and clinopyroxene of the marbles are contemporaneous with forsterite and spinel.

The random orientation of the pargasite suggests that this constituent has been formed during the post-kinematic phase. Probably it has largely replaced both earlier minerals. At a still later stage of the metamorphism, pargasite has been replaced by clinochlore. It is difficult to decide when the phlogopite originated for the first time. Possibly the mica has already been formed during an early stage of the metamorphism (synkinematic) e. g. the phlogopite bands in the marbles. The intimate intergrowths with pargasite may have originated somewhat later than this amphibole. The relations of clinochlore with respect to phlogopite suggest that the mica has been locally recrystallized during the formation of the former mineral. Therefore it is probable that phlogopite has been stable during several successive stages of the metamorphism, the most important development being immediately after the formation of the pargasite.

B. HORNBLENDE-BYTOWNITE-GNEISSES AND BIOTITE-BYTOWNITE-GNEISSES

The most common types of resisters are biotite-bytownite-gneisses and hornblende-bytownite-gneisses. They are in most cases closely associated with one another and form continuous and regularly alternating bands in the inclusions in the quartz-diorites. Rarely, independent bodies of the two rock types have been found.

Occasionally light-coloured clinopyroxene-bearing bands occur in these gneisses.

Thin marble bands can be seen in several inclusions of hornblende and biotite-bytownite-gneiss, whilst once an inclusion has been encountered in which these rock types alternate regularly with quartz-rich marble bands.

a. Biotite-bytownite-gneiss

The bands of biotite-bytownite-gneiss usually have a greyish red (10 R 4/2) colour. Their thickness varies from a fraction of a millimetre to more than a metre. As a rule they are a few centimetres thick. The thicker bands are frequently finely banded: biotitic folia alternate with quartzo-felspathic folia averaging 1 mm in thickness. Often the biotite is more or less evenly distributed.

Microscopy. In a fine-grained aggregate of b y t o w n i t e and q u a r t z, rather well-oriented plates and laths of light brown b i o t i t e occur with an average length of 0.6 mm. In the biotitic folia, the plates are often coarser than elsewhere. Plagioclase (diameter 0.2—0.4 mm) frequently shows a tendency to form elongated grains in parallel arrangement. In the biotitic folia the plagioclase crystals may reach a size of 0.6 mm. The amount of quartz varies in adjacent bands. Where little quartz is present, it occurs as equidimensional or elongated and oriented grains (0.1 mm across) regularly distributed in the aggregate of plagioclase. In bands where the mineral predominates, plagioclase is interstitial. Several times narrow quartz lenses can be seen. The contacts with respect to plagioclase are usually crenulated.

Accessories are o r t h i t e and p y r i t e. T i t a n i t e and i l m e n i t e were rarely observed in the biotite-bytownite-gneisses.

Occasionally small irregular masses of sericite and clinozoisite occur in the plagioclase aggregate.

460 m NW of the cabin of the lake of Artax an inclusion has been found in which bands of biotite-bytownite-gneiss alternate regularly with quartz-rich marble and clinopyroxene-bearing bands. The proportion of quartz is usually large in the biotite-bytownite-gneiss bands. Occasionally they even become quartzizitic.

b. Hornblende-bytownite-gneiss

The hornblende-bytownite-gneisses are dark greenish grey in colour and are usually finely banded. In the thinner bands of this rock type the oriented and elongated hornblende crystals may occur evenly distributed.

Microscopy. The fine banding is produced by difference in the relative amounts of hornblende, plagioclase and quartz. Green hornblende has a pleochroism of n_γ = greyish green (5 G 5/2), n_β = light olive (10 Y 5/4) and n_α = pale greenish yellow (10 Y 8/2) to pale olive (10 Y 6/2). Its average grain size varies between 2 mm in the hornblende-rich folia and 0.6 mm in the quartzo-felspathic folia. Parallel arrangement of the crystals of this mineral is usually evident. They are often deeply embayed and sometimes sieved by quartz and plagioclase (see fig. 33, upper and lower side). In several cases the hornblende has been partly altered into a pale green actinolite. Plagioclase (bytownite) shows the same relations as in the biotite-bytownite-gneisses. Where quartz is plentiful the plagioclase crystals have strongly corroded outlines. Sometimes this mineral is partly altered into sericite and clinozoisite. The amount of quartz varies strongly. In the hornblende-rich folia quartz is least represented. Thin long lenses of quartz are of frequent ocurrence. In an enclave south of Pic de Pioulou quartz is entirely absent.

Accessories are ilmenite, titanite, orthite and apatite. Ilmenite and titanite are much more common than in the biotite-bytownite-gneisses. Pleochroic haloes around titanite in hornblende are rare. Orthite forms elongated grains, enveloped by rims of clinozoisite, which have replaced plagioclase.

In several places, for instance 100 m west of point 1555, the biotite- and hornblende-bytownite-gneisses show a distinct linear texture. Megascopically this is evident by the linear arrangement of the hornblende prisms. Microscopical observations show that the plates of biotite and also the crystals of plagioclase and quartz are elongated in the direction of the lineation.

c. Clinopyroxene-bearing bands

The bands of this rock type have a greenish grey colour (5 GY 6/1) and are less melanocratic than the hornblende- and biotite-bytownite-gneisses. Elongated and oriented crystals of clinopyroxene and hornblende are regularly distributed or form more or less continuous trails in the direction of the banding

Microscopy In a fine-grained mosaic of plagioclase and quartz, continuous trails of crystals of clinopyroxene and somewhat less frequently of green hornblende can be seen. Plagioclase and quartz usually predominate over the melanocratic constituents. The clinopyroxene crystals are elongated and oriented parallel to the banding. Their contacts are always dentated. Occasionally this mineral is sieved by plagioclase. Uralitization of the clinopyroxene invariably gives a pale green actinolite. Plagioclase is in many cases altered into clinozoisite or into sericite.

Alterations of the primary constituents are much more common than in the biotite-bytownite-gneisses and hornblende-bytownite-gneisses.

Zircon, titanite and ore are accessories.

d. Influence of post-kinematic pegmatites

Sills. 400 m south of the Pic de Pioulou a layer of biotite-bytownite-gneiss (half a metre thick) is in contact with a sill of pegmatite. In this layer a band of hornblende-bytownite-gneiss, showing typical boudinage, occurs. The influence of the contact metasomatism imposed by the pegmatite on the adjacent rock is evident. Thin sections of the gneiss along the immediate contact show an alternation of thin folia of biotite, bytownite, quartz and a little potash-felspar with others in which potash-felspar predominates over the other three minerals. The potash-felspar has replaced plagioclase and quartz. The biotite plates are idioblastic and do not show preferred orientation. Bytownite is usually completely fresh. In the hornblende-bytownite-gneiss occurring at a distance of 8 cm from the contact potash-felspar is absent. Plagioclase is almost completely replaced by sericite and a little clinozoisite. Green hornblende which is often sieved by felspar does not show any trace of alteration.

The random orientation of the biotite near the contact of the pegmatite indicates that this rock is post-kinematic. Similar features have been observed along contacts of pegmatite sills in the striped amphibolites (see p. 169).

Unconformable pegmatites. In the biotite- and hornblende-bytownite-gneisses alteration of plagioclase into clinozoisite and sericite may occur. Green hornblende is altered along the grain boundaries and cleavages into a pale green actinolite, which is always sieved by irregular pellets of quartz. Biotite is altered into prehnite and negative pennine. These alterations have been observed everywhere in the resisters of the Trois Seigneurs massif, but are usually not common.

Immediately along the contacts of cross-cutting pegmatites (e. g. 50 m east of the cabin of Artax) the hornblende- and biotite-bytownite-gneisses are strongly altered. The distribution of the altered parts of the rock has to some extent a patchy character. On one hand the plagioclase-rich folia are almost completely replaced by clinozoisite or epidote which may attain sizes up to 1 mm, on the other hand they have been completely altered into sericite. In the sericite irregular grains of clinozoisite are of frequent occurrence. Biotite is usually almost entirely replaced by negative pennine and prehnite and occasionally by positive pennine or clinozoisite. The green hornblende is largely altered into actinolite. Conformable veinlets of adularia replacing quartz and plagioclase are often present.

Oval-shaped grains of apatite with a length of 0.2 to 0.4 mm occur in considerable amounts. This accessory appears to be more common in the altered parts of the rock than where the resisters are still entirely fresh.

It is probable that apatite has been formed to a large extent as a result of contact metasomatism of the pegmatites.

In a band of hornblende-bytownite-gneiss at a distance of half a decimetre from the pegmatite contact the quantity of the alteration products is much smaller than in the example described above. Alteration of green hornblende into actinolite is still fairly common. In several instances small grains of the actinolite with sutured contacts occur independently in the quartzo-felspathic ground mass (see fig. 33). They do not contain relics of green hornblende. Possibly the actinolite has also been formed at the expense of other minerals than hornblende, for instance plagioclase and ore.

At a distance of 1 dm of the pegmatites the alterations of the primary minerals are rather scarce. Occasional veinlets of adularia have been observed.

In conclusion it can be said that the following paragenesis occurs in the

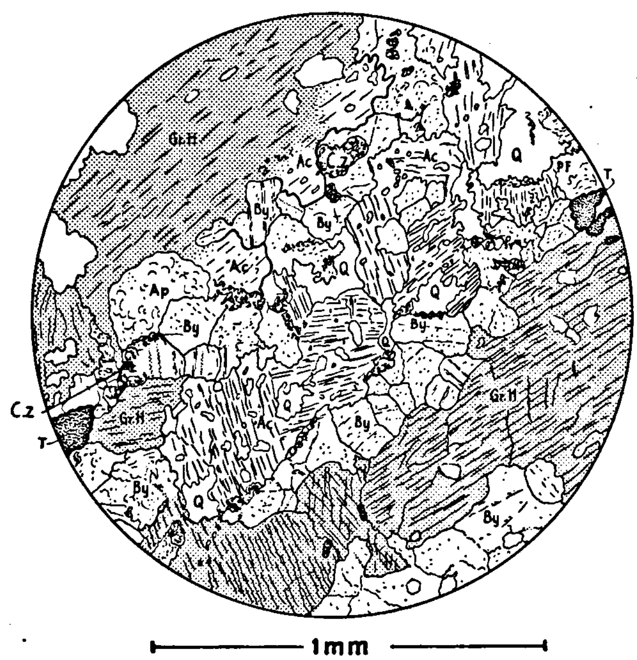


Fig. 33. Late actinolite in hornblende-bytownite-gneiss (5 cm from the contact of a late cross-cutting pegmatite).
Ac = actinolite, Ap = apatite, By = bytownite, Cz = clinozoisite, Gr.H. = green hornblende, PF = adularia, Q = quartz, T = titanite.

hornblende-bytownite-gneisses and biotite-bytownite-gneisses along the contacts of unconformable pegmatites: adularia, sericite, clinozoisite, epidote, actinolite, pennine and prehnite.

e. Conclusions

In most cases, bands of hornblende-bytownite-gneiss and biotite-bytownite-gneiss alternate regularly; occasionally they occur in association with marbles; transitions to quartzitic rocks have been observed several times; these facts prove that the rock types under discussion are of sedimentary origin.

It should be emphasized that in these gneisses the biotite is never intergrown with the hornblende, they are seldom in contact with one another. This may indicate that the occurrence of these constituents in the different bands is solely determined by the original composition of the sedimentary bands.

The structure of the hornblende- and biotite-bytownite-gneisses is such that it may safely be concluded that the Hercynian deformation has clearly put its mark on these gneisses. The influence of static recrystallization apparently has been insignificant.

C. STRIPED AMPHIBOLITE

a. Description

Inclusions of fine-grained amphibolite occur in the amphibolite-rich zone east of lake Artax. In hand specimen an alternation can be seen of dark grey finely striped bands rich in hornblende and medium to light grey felspar-rich layers. Their thickness varies between several millimetres and some centimetres. In the light grey bands very thin and more or less discontinuous streaks of hornblende occur evenly distributed. The whole has a distinct finely striped nature.

Rather large inclusions of fold hinges of this rock type have frequently been found. In the amphibolite itself narrow isoclinal folds occur whose axial planes are parallel to the foliation.

In thin sections the striping of the hornblende-rich bands is seen to be produced by rather small differences in the relative amounts of plagioclase and hornblende. In the plagioclase-rich bands continuous trails of hornblende crystals are of frequent occurrence. Where plagioclase (andesine) predominates it forms a mosaic of grains with a size of 0.2 to 0.3 mm. Thin and very fine-grained bands (average grain size 0.1 mm) are often observed in which plagioclase is more basic (labradorite) than elsewhere. Parallel arrangement of the elongated grains is distinct in these bands. Hornblende shows a pleochroism of n_γ = dusky yellow green, n_β = olive brown, n_α = moderate greenish yellow and n_γ/c appr. 18°. Its grain size varies. In the fine-grained bands with basic plagioclase this averages 0.2 mm and elsewhere 0.6 mm. The elongated and oriented crystals are always strongly embayed by the plagioclase, sieve texture is frequent. Occasionally biotite occurs in thin discontinuous streaks. The plates are well-oriented and average 0.5 mm in length. Titanite, apatite and ore are accessories.

b. Influence of pegmatitic veins

Pegmatite sills with a thickness varying between some centimetres and 2 dm occur in the amphibolite. Up to a distance of a few centimetres along their contacts the striped amphibolite is always entirely biotitized.

In the biotite zones along the contacts of the sills, concentrations of microcline porphyroblasts, averaging 3 mm in size, are of frequent occurrence. In thin sections of such a microclinized zone it can be seen that the porphyroblasts lie in a groundmass of randomly oriented biotite plates and plagioclase with an average grain size of 0.5 mm. Net-texture is well-developed. There is, however, an important difference from the pattern shown in fig. 36. The biotite crystals are always arranged with their longitudinal sections parallel to the contacts of the felspar grains. In contact with potash-felspar the plagioclase crystals show the familiar clear albite rims (see p. 139).

Apatite and ore are accessories, and show a pronounced preference to occur in biotite.

Microcline vanishes at a distance of some centimetres from the contacts of the leucocratic sills. In these parts of the rock the plagioclase is always entirely sericitized.

From the observations the conclusion can be drawn that the amphibolite has undergone a potash metasomatism along the contacts of the leucocratic veins. Here a thorough biotitization of the hornblende is evident, and in many instances microclinization has taken place. The occurrence of randomly oriented biotite along the contacts of the pegmatite sills suggests that these bodies in the amphibolite are post-kinematic. The behaviour of the mica is in complete contrast to that in the microclinized bands in the lime-silicate series of Lapège where the orientation of the biotite is distinct. The fact that the plagioclase is entirely sericitized at a larger distance from the sills indicates that the temperature in the enclosing rock was already rather low during the formation of these sills. Corresponding phenomena have been observed along the contacts of a pegmatite sill south of the Pic de Pioulou (see p. 167).

c. Conclusions

It is probable that the variation in basicity of the plagioclase in the various bands of this rock type is a relic of the original sedimentary banding. In several cases the biotite-quartzites, described below, alternate regularly with the striped amphibolites. Therefore it is suggested that these amphibolites are of sedimentary origin. It should be noted, however, that these possible para amphibolites often contain a plagioclase, which is more sodic than usual in the hornblendic rocks of sedimentary origin in the Trois Seigneurs massif. Possibly this is due to the lack of CaO in the original sediment.

D. QUARTZITIC ROCKS

In several localities e. g. 160 m west of point 1555 and in the amphibolite-rich zone east of the lake of Artax, a collection of hand-specimens was sampled of quartzitic rocks. Some types occur independently, others are intercalated between the hornblende- and biotite-bytownite-gneisses or between the striped amphibolites.

a. Hornblende-bearing quartzite

Small pinkish grey enclaves of this type are rare in the quartz-diorites. On the weathered surfaces thin and parallel streaks of plagioclase are corroded, resulting in a clearly banded rock. In several cases narrow quartz veins which parallel the banding were observed.

In the thin section a mosaic is seen of interlocking grains of quartz and little bytownite. Their average grain sizes are respectively 0.3 and 0.1 mm. The felspar occurs as a rule interstitially. Its quantity varies in adjacent narrow bands. More or less discontinuous trails of elongated plagioclase individuals with a length of 0.6 mm have been found several times. Occasionally elongated and oriented grains of pale green actinolite were observed. The plagioclase crystals are altered to a large extent into sericite and clinozoisite. The actinolite is in many cases largely replaced by clinozoisite.

The structure of the quartz-felspar aggregate shows much similarity with that of quartz-rich biotite-bytownite-gneisses.

b. Garnet-bearing quartzitic biotite-gneiss

Several small inclusions of this type have been found 160 m west of point 1555. Their length is usually 1 m. In hand-specimen it can be seen that pale yellow to light brown fine-grained bands alternate with somewhat less fine-grained yellow grey bands. Their thickness varies between 5 mm and several centimetres. The yellow grey layers are very rich in quartz and always stand out through weathering. Straight and conformable veinlets of quartz of at most 1 mm in thickness are of frequent occurrence.

Under the microscope an aggregate of equidimensional or somewhat elongated and oriented grains of quartz and labradorite can be observed. The grain size of the quartz crystals varies between 0.2 and 0.5 mm in the successive bands. Plagioclase has constantly a size of 0.3 mm. Quartz is abundantly represented, but is somewhat less frequent in the finer grained bands. Plagioclase often shows deeply embayed outlines. Normal zoning has been observed. In several instances rather basic cores of An_{70} were found. Biotite is fairly scarce. It appears in the finer-grained bands as small oriented flakes and in the coarser layers as irregular plates averaging 1 mm in length. On occasion spongy and equidimensional crystals of garnet occur with a maximum size of 1 mm. Accessories are apatite, ilmenite and pyrite.

c. Biotite-quartzite with garnet porphyroblasts

These rocks have a light brown colour of weathering. On fresh surfaces fine-grained, yellowish grey bands can be seen alternating with medium grey biotite-rich layers which contain numerous porphyroblasts of garnet. On weathered surfaces parallel to the banding, these porphyroblasts are carved out. They attain a maximum size of 2 cm.

This rock type occurs regularly in the western side of the amphibolite-rich zone east of the lake of Artax. The inclusions may have fairly large dimensions. In most cases the biotite-quartzites are intercalated with the striped amphibolites.

Thin sections of the light-coloured bands show a mosaic chiefly of quartz crystals with interlocking contacts. Irregular grains of plagioclase (An_{53}) and rudely oriented biotite plates are sparsely distributed. Their grain size averages 0.3 mm. In some narrow layers potash-felspar is plentiful, forming small grains of 0.2 mm in size. In these layers the quartz varies in grain size. The potash-felspar is late and has replaced the quartz.

In the darker coloured bands, biotite is abundant next to quartz. The mica plates show a rude orientation. Garnet forms elongated and oriented grains. They are sieved with elongated crystals of quartz and plates of biotite which show parallel arrangement. Between the garnet porphyroblasts, continuous trails of long-drawn plagioclase (bytownite) grains, with a length of 0.6 mm, appear occasionally. Biotite and garnet are sometimes partly altered into negative pennine. Plagioclase is in many cases slightly sericitized.

PART II. ROCKS OF IGNEOUS ORIGIN

E. FINE-GRAINED LINEAR HORNBLENDE-BIOTITE-GNEISS

a. Description

Near point 1555 (fig. 29); 200 m SE and also 200 m WSW of this point along the creek of the lake Artax; 1200 m south of the lake Artax (east of point 1733) small inclusions of mica-bearing rock occur in quartz-diorite. They are medium grey and sometimes brownish grey in colour, fine-grained in texture and homogeneous. Thin discontinuous streaks of biotite occur regularly distributed. Linear texture is always distinct and is expressed by a fine crumpling of the micas on planes parallel to the foliation. In these gneisses lenticular patches are to be seen, in which the rock has a coarser grain size than usual and contains randomly oriented micas. Once an inclusion of hornblende-biotite-gneiss has a marginal zone of such a less fine-grained rock.

Microscopy. The mineralogical composition of the different enclaves varies somewhat. As a rule biotite, hornblende and plagioclase each, are present in equal amounts. The quantity of quartz is never large.

Biotite builds either small crystals or larger deeply embayed plates of at most 1 mm in length which are very well oriented. The larger plates may occur evenly distributed, but in most cases they form discontinuous parallel streaks. Hornblende occurs in three varieties. Light green hornblende with a pleochroism of n_γ = pale olive, n_β = pale to light olive and n_α = greyish yellow green, is present in most cases. In two inclusions (656 and 667) a colourless cummingtonite was found and in the granitized enclave of point 1555 a green hornblende occurs with n_γ = greyish green (10 GY 5/2), n_β = dusky yellow, n_α = greyish yellow green. As a rule the prisms of this mineral show a distinct linear arrangement. The dimensions of the hornblende crystals vary between 0.2 and 2 mm. The larger individuals occur either evenly distributed or in trails which may or may not be associated with the streaks of biotite. In the coarser recrystallized parts of the enclaves, the hornblende is randomly oriented, while very often intimate intergrowths with plagioclase have been observed. Plagioclase (labradorite) is usually elongated in the direction of the lineation. Its grain size is not variable and the length of the crystals is approximately 0.2 mm. The contacts of the individuals are mostly not irregular, but in several cases they are sutured with respect to hornblende. In the coarser patches the plagioclase crystals are deeply embayed and also sieved by quartz. Quartz occurs as small elongated and oriented grains. In the coarser recrystallized lenses the mineral attains dimensions of 1 mm. It corrodes strongly all the other components in these parts of the rock.

b. Influence of leucocratic quartz-diorites

The body of hornblende-biotite-gneiss as illustrated in fig. 29 is penetrated by veins of leucocratic quartz-diorite. At the contacts of the leucocratic veins and the resister there is a thin band of approximately 1 mm thickness consisting of biotite plates averaging 0.6 mm in length. In the melanocratic rock adjoining this biotite concentration a fine-grained band occurs with relatively little biotite. At a distance of about 3 mm from the contact the quantity of the mica increases rapidly, until it occupies more than half of the volume. In this biotite-rich band idioblastic hornblende prisms are sparsely distributed. Only at a distance of 5 mm of the contact of the sill the hornblende becomes more frequent, whereas the quantity of the biotite accordingly decreases a little. Further away from the contacts of the leucocratic sills the hornblende, biotite and the plagioclase-quartz aggregate each are present in equal amounts. At the contacts between both rock types the basicity of the plagioclase is equal to that of the plagioclase of the leucocratic quartz-diorite (andesine). In the enclave the basicity increases rapidly until at a distance of 3 mm from the boundary between both rock types bytownite is present. In the contact zone of the fine-grained gneiss no trace of disorientation of the biotite was seen and the sparsely distributed hornblende prisms likewise show a distinct linear arrangement. In the thin sections of this rock, more or less close to the contacts of the sills, no alteration products of plagioclase, biotite or hornblende were observed at all. This is entirely in contrast to the phenomena appearing along the contacts of unconformable pegmatites.

The distinct orientation of biotite and hornblende along the contacts of the leucocratic rock suggests that the contact actions of the leucocratic sills on the enclosing rocks have ceased before the end of the Hercynian deformation.

c. Conclusions

These gneisses are never intercalated with types of resisters of sedimentary origin. Typical sedimentary banding was not observed. Therefore it is improbable that the hornblende-biotite-gneisses are of sedimentary origin.

Probably the patches, in which the rock is coarser-grained than elsewhere and does not show foliation, were formed as a result of static recrystallization.

F. AMPHIBOLITES

a. Fine-grained amphibolite

On fresh surfaces these fine-grained and homogeneous rocks are greyish black in colour. Hornblende which is abundantly represented always shows a linear arrangement. Occasionally biotite is present in small amounts.

The length of the bodies of this rock type is up to 5 m. They have been encountered 100 m NE and 680 m ENE of the Pic de Pioulou and also immediately north of Junac near the track from this village to Lapège. Contacts with the enclosing quartz-diorites are sharp.

Microscopy. A typical example of this rock type in a thin section almost perpendicular to the direction of the lineation is given in fig. 34. Green hornblende with a pleochroism of n_γ = greyish green, n_β = light olive and n_α = light greenish yellow, is in the form of prisms with a length up to 1 mm. Their linear arrangement is distinct, though there are exceptions. On occasion the mineral is partly altered into an actinolite. The crystals of plagioclase (bytownite) are usually elongated in the direction of the lineation. They are on an average 0.1 mm wide and 0.2 mm long. Larger individuals measuring 0.3 to 0.4 mm, are sieved with quartz. Inverse zoning has been observed several times. Alterations into sericite and clinozoisite are rare. In the enclave near Junac the plagioclase is to a large extent sericitized and albitized. Biotite is sparsely distributed and forms oriented subhedral plates averaging 0.7 mm in length. Quartz forms either small equidimensional grains of 0.1 mm size or narrow lenses parallel to the foliation. In the variety occurring near Junac this mineral is not present.

Accessories are apatite, ilmenite and pyrite. The latter constituent occurs usually in association with fine cross-cutting veinlets of adularia.

The mineralogical composition of one of the varieties is: hornblende 63.9 %, plagioclase 20.0 %, quartz 7.6 %, biotite 5.3 %, accessories 3.2 %.

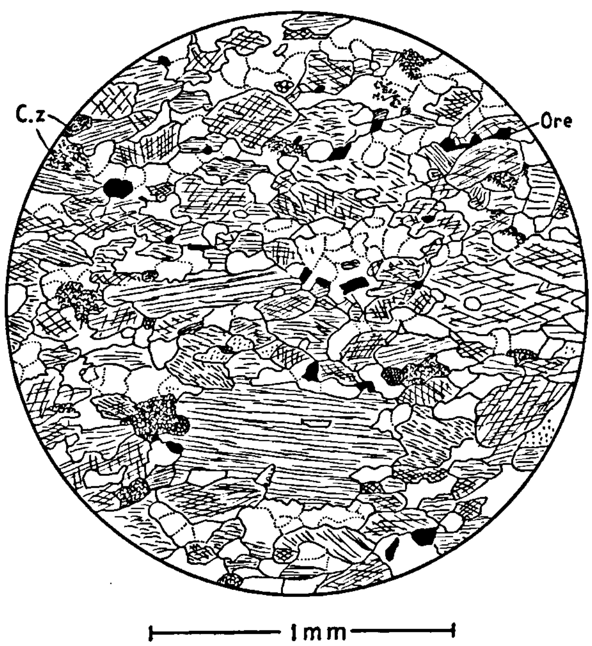


Fig. 34. Fine-grained amphibolite approximately perpendicular to the lineation. Cz = clinozoisite.

b. Clinopyroxene-bearing amphibolite with linear texture

Nearly 1200 m south of the lake of Artax a body of amphibolite with a size of 10 × 40 m has been found in quartz-diorite. In the outcrop more or less discontinuous bands of pale olive clinopyroxene-bearing gneiss can be seen in greyish black homogeneous amphibolite. Their thickness varies between 1 mm and a few centimetres. The thicker bands are in itself finely banded. The distribution of these pale bands is rather irregular. In most cases the dark coloured amphibolite greatly predominates. Linear arrangement of the hornblende prisms is always very conspicuous.

Under the microscope an approach to banding was observed in the amphibolite. Bands consisting almost exclusively of green hornblende alternate with plagioclase-bearing bands. In thin sections perpendicular to the lineation the hornblende-rich bands appear as a packed aggregate of oriented rhombs with a length of 0.3 mm. Occasionally larger crystals occur which are unoriented. In plagioclase-bearing bands the hornblende is beautifully euhedral. The prisms of this constituent are several millimetres in length. The green hornblende shows a pleochroism of n_γ = greyish olive, n_β = moderate olive brown, n_α = greyish yellow green. In the cores of larger crystals a clear green variety has been found. Occasionally this mineral is partly altered into actinolite. Plagioclase (An_{58}) shows parallel arrangement and averages 0.2 mm. Inverse zoning has been observed. Locally the plagioclase is altered into sericite, clinozoisite and albite. In the albitized parts irregular plates of prehnite, 1 mm in diameter, have been found which replace the plagioclase aggregate. The alteration products of plagioclase are fairly common in the clinopyroxene-bearing bands. Well-oriented prisms of clinopyroxene with a length of 1 to 2 mm occur in continuous trails. They have often indented contacts and are sometimes deeply embayed by plagioclase. In thin sections perpendicular to the lineation intimate intergrowths with hornblende are observed. A number of euhedral rhombs of hornblende always occur in the clinopyroxene. Frequently these islets show the same optic and crystallographic orientation as hornblende crystals adjoining the pyroxene. In many cases the latter mineral is partly altered into actinolitic hornblende and prehnite.

Apatite, titanite and ilmenite are accessories.

c. Ilmenite-bearing amphibolite

On the ridge between Illier and Lapège, 500 m SE of point 1256, a conformable lense of amphibolite occurs in the sillimanite-gneisses. This lense has a length of 5 mm and a width of at most ½ m. The amphibolite is homogeneous, greenish black in colour and medium-grained in texture. Foliation is distinct, but linear texture is not evident. Discontinuous trails of elongated plagioclase grains are rather scanty. Flakes of biotite occur sparsely but evenly distributed.

Along the track from Illier to Lapège, ESE of the first-named locality, another conformable band of amphibolite occurs. This rock is of the same type as the first one, but has a somewhat lighter colour. Biotite is more frequent than in the sill on the ridge, and forms thin continuous streaks which are evenly distributed.

Microscopy. Hornblende shows a pleochroism of n_γ = light olive grey, n_β = greyish olive, n_α = pale olive. It occurs as well-oriented and elongated crystals with irregular outlines. The average size is 0.6 × 2.5 mm. Along their contacts the hornblende individuals are sometimes altered into actinolite. Plagioclase (An_{70-76}) forms either elongated and oriented grains with an average length of 1½ mm or small euhedral inclusions in hornblende (see fig. 35). The two minerals may show intimate intergrowths. From the hornblende individuals numerous grasping arms appear to penetrate deeply into the plagioclase (see fig. 35). The latter in its turn penetrates the hornblende crystals, though less often, and divides them into several islets. There may be small patches of somewhat more acid plagioclase in the cores of the bytownite crystals. Ilmenite is fairly abundant. Pyrite is not common. Small randomly oriented plates of biotite are sparsely distributed. Quartz builds, either small oval-shaped grains (quartz I) of 0.1 mm length in plagioclase and at grain boundaries between hornblende and plagioclase, or irregular grains of 0.2 mm size (quartz II), showing no connection with the just-mentioned ovals. Other accessories include **a p a t i t e** and **z i r c o n**.

The variety along the track shows some differences as compared with the amphibolite just-described.

1) Part of the hornblende and plagioclase shows a more advanced stage of intergrowth. Here the hornblende often has a skeletal appearance (see under quartz-gabbros, p. 181). The green hornblende is to a large extent changed into a colourless polysynthetically twinned cummingtonite.

2) The quantity of ore is very low. On the other hand biotite is more frequent. This mineral is in many cases intimately intergrown with hornblende. It seems as if the mica has replaced the latter. Alterations into

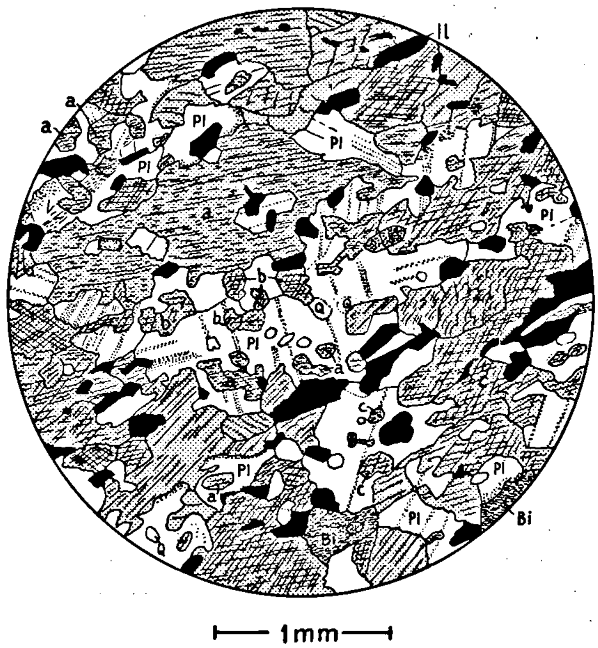


Fig. 35. Ilmenite bearing amphibolite.
Bi = biotite, Pl = plagioclase, Q = quartz.
The hornblende islets indicated with a, b and c respectively, show optic continuity.

negative pennine, titanite and epidote have been observed several times. Occasionally the biotite is split by prehnite lenses.

3) Quartz is likewise more frequent. Apart from the modes of occurrence described above, this mineral occurs interstitially to plagioclase and biotite and more rarely to plagioclase and hornblende. The interstitial crystals have dimensions of 3 to 6 mm. The irregular inclusions of quartz in plagioclase always show optic continuity with the larger individuals outside. Probably this quartz (II) is later than the oval-shaped individuals (quartz I).

Hydrothermal veinlets traverse the rocks. In plagioclase they are filled with albite, in hornblende and biotite with negative pennine and in ilmenite with titanite.

It is probable that the biotite-bearing variety was more severely attacked than the ilmenite-bearing amphibolite by the processes active during a certain stage of the post-kinematic phase. It is assumed, that during this stage in the biotite-rich amphibolite the following has happened (see also under quartz-gabbros, p. 183).

1) A large part of green hornblende is changed into cummingtonite.

2) The hornblende and plagioclase have formed very intimate intergrowths. Each of the two varieties described above represents a different stage of intergrowth.

3) Biotitization took place probably at the expense of the hornblende and also of ilmenite.

4) By possible metasomatic action quartz (II) also originated.

d. Garnet-bearing amphibolite

Along the road Niaux-Lapège, 60 m east of the lunch tree several flat-lying bands of garnet-bearing amphibolite, occur in quartz-diorite. The hand-specimens show numerous elongated and oriented minute specks of plagioclase and quartz in a black grey mass of hornblende. Moderate red garnet porphyroblasts with a size of 3 to 6 mm are of frequent occurrence.

Microscopy. G r e e n h o r n b l e n d e has a pleochroism of n_γ = greyish green, n_β = greyish to light olive and n_α = pale olive. The mineral is to a large extent changed into colourless cummingtonite. Its average length is 1½ mm. The hornblende prisms are well-oriented. Plagioclase and hornblende frequently show intimate intergrowths similar to those in the biotite-rich variety of ilmenite-bearing amphibolite just-described. P l a g i o c l a s e (An_{69}) is elongated in the direction of the foliation and has an average size of 0.5 mm. The contacts are always irregular. The mineral is as a rule sieved by ovals and vermicules of quartz which have a length of 0.1 mm at most. Twinning is very general. Sericitization has been observed in association with albite and chlorite veinlets and also around grains of orthite. Q u a r t z occurs 1) in non-granular veinlets of at most 1 mm in width, lying parallel to the foliation, 2) in lenses or as irregular grains of at most 1 mm in size and 3) as poeciloblastic inclusions in plagioclase or garnet. I l m e n i t e in elongated grains is fairly well represented. Pink g a r n e t appears as elongated porphyroblasts which are sieved by quartz, plagioclase and rarely by hornblende. Pale reddish brown o r t h i t e and apatite are accessories. The orthite is sometimes surrounded by thin rims of clinozoisite.

Integration of one thin section resulted in: hornblende 34.8 %, plagioclase 33.1 %, quartz 17.1 %, ore 9.7 %, accessories 5.3 %.

e. Conclusions

In most cases a linear arrangement of the hornblende prisms and the plagioclase crystals is very distinct in the amphibolites. Therefore it is justified to conclude that these minerals are synkinematic. The biotite in the amphibolites often does not show orientation and it is assumed that this mineral has replaced hornblende during the post-kinematic phase. In many cases the synkinematic green hornblende is replaced by cummingtonite. Based on observations in the quartz-gabbros which will be described below it is accepted, that the cummingtonite is post-kinematic.

The intimate intergrowths between hornblende and plagioclase, which occur in some varieties of amphibolite, are very common in the quartz-gabbros. They are considered as incipient stages of the formation of the quartz-gabbros.

The amphibolites are always homogeneous and never show distinct traces of banding. They are not intercalated with resisters of sedimentary origin. The contacts of amphibolite bodies with enclosing synkinematic gneisses are always sharp. For these reasons it is probable that these rocks have originated at the expense of volcanic or other igneous rocks.

G. HORNBLENDE-DIORITE

Lenticular bodies of hornblende-diorite have been found along a track at a distance of 400 m west of Illier and along the Niaux-Lapège road nearly 200 m NE of the most southerly hairpin bend. These bodies are enclosed by, respectively quartz-diorite and leucocratic gneiss. In the latter locality the rock is sometimes homogeneous and massive. The samples show an abundance of equidimensional clots of hornblende, 2 to 3 mm in size which are regularly distributed in a fine- to medium-grained mass of felspar. Clusters of biotite are of frequent occurrence. In other hand-specimens of the same locality the biotite clusters are elongated and show a parallel arrangement. The biotite crystals are however, randomly oriented. In these cases the aggregate of plagioclase and hornblende also shows a slight foliation. Near Illier a pronounced linear texture can be seen in the rock, the clusters of hornblende are strongly elongated in the direction of the lineation. In this locality the biotite is sparsely distributed and builds randomly oriented plates.

Microscopy. P l a g i o c l a s e forms a granoblastic mosaic of crystals showing no interlocking contacts. Most of the plagioclase has a grain size of 0.4 to 0.6 mm. There are also larger subhedral crystals, measuring 1 to 3 mm, either separate and regularly distributed or close together in groups. The contacts with hornblende are in general not irregular. Interfingering intergrowths between plagioclase and hornblende are of local occurrence. They resemble strongly to those described on p. 176. Zoning occurs frequently especially in the larger crystals. Basic cores (An_{60-63}) have mostly a distinct euhedral shape. Several times crystals are seen with a more acid core (An_{47-50}), surrounded by an euhedral basic zone (An_{60-80}) and a more acid outer rim (An_{40-45}). These phenomena are similar to those observed in the quartz-dioritic gneisses (Chapter IV, p. 126). In many cases the basic parts of the crystals are sericitized. Twinning is very general. G r e e n h o r n b l e n d e is always anhedral. The mineral is to a large extent altered into a colourless cummingtonite. In parts of the rock where plagioclase and hornblende occur in equal amounts, the grain size is 0.3 mm. In the clusters a size of 1 to 2 mm is reached. B i o t i t e builds either separate crystals or clusters of irregular plates. The latter always have strongly corroded outlines with respect to plagioclase and quartz. The mica is often intimately intergrown with hornblende. Possibly this mineral has replaced the hornblende. Q u a r t z was found in small quantities or is absent. It forms either elongated lenses or irregular interstitial grains.

Z i r c o n, a p a t i t e, r u t i l e (as fine needles in biotite), i l m e n i t e and p y r i t e are accessories.

Hydrothermal replacement veinlets were frequently observed. In plagioclase they contain albite and in green hornblende or cummingtonite they contain actinolite.

In the linear variety the hornblende clusters are arranged in a columnar fashion, the c-axes of the hornblende crystals themselves parallel the direction of the lineation. The plagioclase is often elongated in the direction of lineation.

The mineralogical composition of the different varieties is as follows:

	Plag.	H.bl.	Biot.	Qu	+ acc.
Near Illier	34.5	57.8	5.4	—	2.3
Near Lapège	43.4	31.5	17.8	5.7	1.6

The body of hornblende-diorite with directionless texture is enclosed by synkinematic gneisses. Therefore it is not probable that its linear texture has been lost by the influence of static recrystallization during the post-kinematic phase. It is more likely to admit that the Hercynian deformation in the rock series locally had less influence, by which the original massive texture of the rock under consideration has been preserved.

In this rock type it is clear that actinolite is later than the cummingtonite. Probably the latter mineral is post-kinematic.

H. QUARTZ-BEARING HORNBLENDE-GABBRO

An inclusion of a gabbroic rock occurs near point 1555. Many hornblende prisms of at most 5 mm length occur in an aggregate of plagioclase. These prisms show a rudely linear arrangement. Large irregular plates of biotite showing no preferred orientation are evenly distributed.

Microscopically one sees fairly well-oriented prisms of green hornblende between elongated and oriented euhedral plagioclase crystals with a length of 1 to 2 mm. Small and more acid patches (An_{62-63}) occur frequently in the basic plagioclase (An_{77}). The inverse zoning is however, not very typical. Small euhedral inclusions of plagioclase occur several times in hornblende. Untwinned crystals of this felspar are not common.

Green hornblende with n_γ = dusky yellow green, n_β = light olive and n_α = pale olive, is not so distinctly euhedral as it seems megascopically. Plagioclase often embays the hornblende. The linear arrangement of the hornblende prisms is distinct on a microscopical scale, although with frequent exceptions. Biotite builds large irregular plates. They grow right across the plagioclase-hornblende aggregate and sometimes have a skeletal appearance. Intimate intergrowths with hornblende were frequently observed. It seems that the biotite has replaced the hornblende. The mica is frequently wedged by prehnite lenses. Quartz is in the form of interstitial crystals, which have a size up to 1½ mm. Locally this mineral corrodes the other constituents, especially plagioclase.

Ilmenite, apatite, titanite and orthite are accessories.

The mineralogical composition of this rock is as follows: plagioclase 52.5 %, hornblende 21.0 %, biotite 11.5 %, quartz 10.5 %, accessories (mostly ore) 4.5 %.

It is possible but not probable that the linear texture of this gabbro is a relic of a flow structure which originated during its intrusion. The inverse zoning of the plagioclases and the absence of pyroxene and other

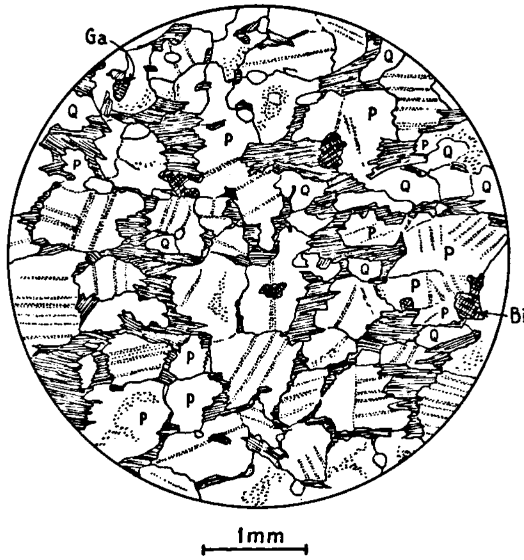


Fig. 36. Biotite-diorite-gneiss showing net-texture.
Ga =garnet.

Fig. 37. Pre-microcline(?) myrmekite in biotite-diorite-gneiss.
Bi = biotite, P = plagioclase, PF = microcline, Q = quartz, Ap = apatite.

igneous relics indicate that the processes which were active during the metamorphism had a thorough effect. Apparently the Hercynian deformation has not produced a pronounced linear texture.

I. BIOTITE-DIORITE GNEISS

Along the Niaux-Lapège road, opposite the lunch tree, several horizontal and sometimes isoclinally folded bands of about 50 cm thickness occur in quartz-diorite. They consist of a granular and homogeneous rock, light grey in colour and fine- to medium-grained in texture.

Under the microscope an aggregate is seen of isometric and sometimes elongated and oriented plagioclase grains (An_{25}) between which biotite is present. The cleavages of the mica crystals are well oriented. The rock shows a typical net-texture (fig. 36). In adjacent layers the average grain size of the plagioclase varies between 0.3 to 1 mm. Garnet was found as an accessory. Small oval-shaped grains of quartz are sparsely distributed. In a certain band the quartz is somewhat more abundant than elsewhere. It forms either vermicular individuals in the plagioclase or is interstitial between biotite and plagioclase. Microcline occurs in this band only and shows a tendency to force its way to the quartz vermicules (see fig. 37). It seems that the microcline is later than the vermicular quartz. In this case we may perhaps speak of myrmekite. Possibly this is pre-microcline-myrmekite (F. K. DRESCHER-KADEN, 1948).

Rocks consisting almost entirely of plagioclase and biotite have also been found in the micaschists.

PART III. PECULIAR ROCK TYPES

K. QUARTZ-GABBROS

Lenticular bodies of quartz-gabbro have been encountered in complexes of strongly homogenized quartz-diorite. Other types of resisters are absent in these complexes. The length of the inclusions varies from 0.5 to 5 m. The quartz-gabbros can be very melanocratic and fine-grained; in most cases they are medium-grained and somewhat less melanocratic. In the field the latter are often difficult to recognize. Contacts with the enclosing rocks are always sharp. The following types can be distinguished: a) fine-grained biotite-quartz-gabbro, b) medium-grained-biotite-quartz-gabbro, c) biotite-amphibole-quartz gabbro, d) biotite-bearing amphibole-quartz-gabbro. In general these rocks are massive, the medium-grained biotite-quartz-gabbros still show an approach to foliation.

a. Fine-grained biotite-quartz-gabbro

Small inclusions of this type are present in two places: 100 m south of point 1,555 and on the south side of a steep wall of quartz-diorite on the eastern slope of the ridge between the Pic de Pioulou and Hioula at an altitude of 1,980 m. These rocks are rich in biotite and have a hornfels-like appearance.

Under the microscope a fine-grained aggregate of irregular plates of biotite, euhedral to anhedral plagioclase (An_{79-86}) and quartz is seen. Plagioclase is always sieved with quartz. Amphibole is present in the outcrop near the Pic de Pioulou. This mineral forms small clusters and is largely replaced by biotite.

b. Medium-grained biotite-quartz-gabbro

About 100 m east of the NE extremety of the lake Artax a considerable quantity of lenticular bodies occurs in quartz-diorite. They are coarser in grain and a little more melanocratic than the enclosing rock. In hand-specimen the biotite shows a rude orientation. Especially the larger crystals of the mica are very irregular in shape, they often contain small white specks of plagioclase.

Microscopy. Plagioclase (An_{87}) averaging 4 mm in size is abundant. The crystals are partly sieved by quartz. Variations in basicity have not been observed. Biotite is regularly distributed or forms small clusters in which intimate intergrowths with light green amphibole were seen. Shapeless crystals of quartz lie between the other components.

c. Biotite-amphibole-quartz-gabbro

In the locality mentioned above between the Pic de Pioulou and Hioula another inclusion of quartz-gabbro is present. This rock is light grey in

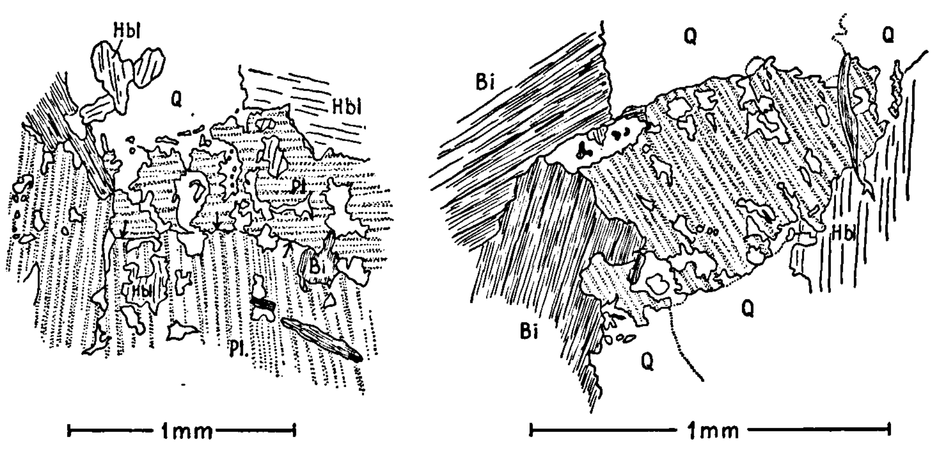


Fig. 38. Basic plagioclase which is sieved by quartz (quartz-gabbro). The quartz islets in the plagioclase crystals show optic continuity with external quartz. The arrows indicate a compositional plane of a twin.
Bi = biotite, Hbl = light green amphibole, Pl = plagioclase, Q = quartz.

colour and medium-grained in texture. Megascopically felspar, biotite and a little amphibole are visible. Quartz is hardly seen.

Microscopy. Plagioclase (An_{82}) is plentiful. Variations in basicity have not been observed, twinning is very general. This mineral is in the form of subhedral crystals which in many cases are sieved by quartz (see fig. 38 a and b). The quartz islets always show optic continuity with irregular quartz individuals outside the plagioclase. Light green amphibole with n_{γ} = greyish yellowish green, n_{β} = pale olive, n_{α} = yellowish grey, is at most 1 mm in size. This mineral forms in most cases skeletal crystals which are enclosed by plagioclase. In quartz they are usually subhedral. Biotite occurs as irregular plates of varying sizes replacing hornblende. Quartz always penetrates between the grain boundaries of biotite and hornblende and of biotite and plagioclase, but never between those of hornblende and plagioclase.

An important accessory is apatite in small euhedral prisms or needles of at most 1 mm in length. In their cores the crystals have a brownish black colour. The colour is caused by an extremely fine pigment. Coloured apatites in contaminated igneous rocks are described e. g. by G. BAKER (1914).

d. Biotite-bearing amphibole-quartz-gabbro

260 m NNE of point 1733, south of the Pic de Querquéou, an elongated body of medium-grained quartz-gabbro with straight contacts has been found. Its thickness is 0.8 m and its length at least 5 m. This body has a fine-grained marginal zone of 5 to 10 cm width. Weathered surfaces of the rock show a greyish white mass of felspar and little quartz in which a black mineral occurs with a distinct prismatic shape. These apparent prisms are at most 5 mm in length and are regularly distributed. In many cases they form clusters and show a fan-shaped arrangement. Biotite is not frequent.

Microscopy. Plagioclase (An_{72}) is plentiful and builds euhedral prisms averaging 3 mm in size. They are largely sieved by quartz. Light green amphibole has a pleochroism of n_γ = greyish yellow green, n_β = pale olive, n_α = yellowish green and is often polysynthetically twinned. The mineral occurs in elongated aggregates, with straight contacts, consisting of small irregular grains. Undoubtedly these aggregates are pseudomorphs after a pre-existing prismatic mineral. Here we have therefore, strong evidence that the light green amphibole, occurring so generally in the quartz-gabbros is of secondary origin.

Light brown biotite forms either small clusters in the interstices between the plagioclase crystals or strongly corroded plates in plagioclase and quartz, replacing hornblende. Quartz builds either angular crystals or is interstitial. Ore and apatite are accessories.

In the fine-grained marginal zone a colourless cummingtonite is present. This mineral has a very irregular shape. Like biotite and quartz it occurs evenly distributed between the plagioclase prisms. These prisms are completely sieved by quartz. As is usual in the quartz-gabbros the quartz inclusions show optic continuity with quartz lying outside the felspar crystals.

Summarizing the quartz-gabbros show the following properties in which they differ clearly from amphibolites and biotite-hornblende-gneisses:

1) Variations in basicity do not occur in the plagioclase crystals.

2) The euhedral shape of the plagioclase crystals is in general distinct.

3) Light green amphibole or cummingtonite occur, which are probably of secondary origin (see for instance under biotite-bearing hornblende-quartz-gabbro).

4) Amphibole and plagioclase are in general intimately intergrown. The former mineral usually has a finely skeletal appearance and is often completely enclosed by euhedral plagioclase crystals. This indicates that the

euhedral shape of the felspar is not a relic of some original igneous texture, but the result of recrystallization.

5) Biotitization of the hornblende is more frequent than in the amphibolites.

6) The plagioclase is as a rule entirely or partly sieved by quartz. Furthermore, the latter mineral shows a pronounced tendency to penetrate between the grain boundaries of the other constituents except between those of plagioclase and amphibole.

7) The quartz-gabbros are in most cases unfoliated.

e. Origin

The quartz-gabbros do not show foliation, they occur in complexes of strongly homogenized quartz-diorite. This might indicate that they have been formed as a result of extreme static recrystallization at the expense of other types of resisters.

It is likely that the observed structures appearing sometimes in the amphibolites, hornblende-gabbros and biotite-hornblende-gneisses, which are identical to those in the quartz-gabbros, represent incipient stages of the formation of the latter rock type (see p. 178).

L. CORDIERITE-ANTHOPHYLLITE ROCK

Along the trail between the lake of Artax and the Col de Lastris about 700 m ENE of the cabin of Artax a small lenticular body of cordierite-anthophyllite rock has been encountered in quartz-diorite. In hand-specimen this rock is dark brown in colour and massive in texture.

In thin sections an aggregate is seen of coarser crystals of cordierite with a size of at least 2 cm. Anthophyllite is regularly distributed in the cordierite and forms irregular and skeletal crystals (1 mm in size) with a shape similar to those of the amphibole crystals in the quartz-gabbros. Plagioclase (oligoclase) and quartz are present in small amounts.

Accessories are rutile (as euhedral or oval-shaped crystals), corundum, spinel, zircon, and at least two other minerals which have still to be determined.

Occasionally the cordierite is replaced by irregular plates of a chlorite mineral, possibly clinochlore.

This body of cordierite-anthophyllite rock has a 2 dm-thick marginal zone consisting of biotite. The observations showed that the biotite is later than the anthophyllite.

The absence of foliation in this rock suggests, that it has been strongly influenced by the processes which were active during the post-kinematic phase.

A complete description of this rock will be given in a future publication.

M. CONCLUDING REMARKS

In table V a review is given of all types of resisters which have been found in the Trois Seigneurs massif.

Sedimentary rocks. It was possible to establish that a sedimentary series of marbles, marls (hornblende- and biotite-bytownite-gneisses) and quartzites is present in the quartz-diorites of the Trois Seigneurs massif. In many cases these rock types are intercalated. Transitional types between marbles, hornblende- and biotite-bytownite-gneisses and quartzitic rocks have been observed several times.

Hornblende-bytownite-gneisses, biotite-bytownite-gneisses and also marbles are the most common types of resisters in the Trois Seigneurs massif. Quartzites are very rare.

The striped amphibolites form a particular type; they consist of hornblende and andesine or labradorite, and sometimes contain a little quartz. The presence of andesine instead of a more calcic plagioclase is possibly due to the lack of CaO in the original sediment, by which the development of more basic plagioclase was prevented.

It is probable that in general the influence of alkalimetasomatism on the resisters of sedimentary origin has been small. This conclusion is based on the omnipresence of very basic plagioclase in these rocks. Biotitization of the hornblende is also rather rare. It was even made probable that the presence of biotite and hornblende in the different bands of the hornblende- and biotite-bytownite-gneisses was controlled by the original composition of the sedimentary layers (see p. 169). In this respect the series of marbles and lime-silicate rocks occurring near Lapège (see p. 159) is an exceptional case. Replacement pegmatites occur frequently in these rocks. It could be proved that the influence of microclinization was locally very important during the synkinematic phase. Plagioclase shows normal zoning and is always more sodic than the plagioclase from other types of resisters with the same mineralogical composition. Possibly the alkali metasomatism has prevented the development of the paragenesis diopside-grossularite-bytownite which is frequently present in other places of the mapped area.

Igneous rocks. The types of resisters which have been described in part II of this chapter (see lower part of table V) are much less common in the mapped area than hornblende-bytownite-gneisses, biotite-bytownite-gneisses and marbles. Banding is never evident in these rock types. They do not occur in association with resisters of which a sedimentary origin is certain, but they form either separate inclusions in quartz-diorite or conformable lenses in synkinematic gneisses. The plagioclases in these rocks frequently show inverse zoning. This may be an indication that the influence of alkali metasomatism on these rocks was very small during the Hercynian metamorphism. Besides plagioclase, hornblende appears without exception. Clinopyroxene, which is possibly contemporaneous with the synkinematic green hornblende, was only found in one inclusion. Alterations of green hornblende into cummingtonite, and during a later stage into actinolite, are frequent.

The synkinematic structure of the resisters has generally been well preserved. Small parts of the inclusions of the linear hornblende-biotite-gneisses are strongly influenced by static recrystallization.

Quartz-gabbros show certain typical properties which differ completely from those of the other types of resisters. Firstly they occur in the quartz-diorites where the effect of homogenization has been very thorough. They do not show foliation. Intimate intergrowths between amphibole and plagioclase and between quartz and plagioclase also occur. It is suggested that these rocks originated at the expense of other types of resisters as a result of extreme static recrystallization by which they obtained quite a new appearance.

Incipient stages of the formation of the quartz-gabbros were observed in some types of amphibolite and in the linear hornblende-biotite-gneisses.

Mineral associations. In table V the periods of stability of the minerals during the different stages of metamorphism are indicated.

Synkinematic paragenesis. It was possible to distinguish a synkinematic paragenesis which can be placed in the amphibolite facies. Water-free minerals are always present in the magnesian and non-magnesian marbles and associated lime-silicates. Plagioclase, green hornblende and biotite occur in the amphibolites and hornblende- and biotite-bytownite-gneisses.

Post-kinematic paragenesis. Alteration of the synkinematic minerals from lime-silicate bands of the non-magnesian marbles apparently did not take place during the earliest stages of the post-kinematic phase. In the magnesian marbles and associated lime-silicates clino-humite and pargasite have replaced the pre-existing constituents. The minerals from the hornblende- and biotite-bytownite-gneisses do not show any trace of alteration. In the rocks of igneous or volcanic origin green hornblende is altered into cummingtonite and a light green amphibole. The classification of this light coloured amphibole in the early postkinematic paragenesis is based on the fact that they are typical of the quartz-gabbros. These rocks are considered as products of extreme static recrystallization. In contrast to basic plagioclase epidote is not stable in the early post-kinematic association. Therefore it may be concluded that after the termination of Hercynian deformation the temperature remained on the same level for a certain period. Of course it is not warranted to place the mineral association under consideration in the amphibolite facies (see for instance H. RAMBERG, 1954, fig. 73). In comparison with the synkinematic paragenesis there appears an important difference, namely the newly formed minerals always contain OH-groups.

Retrograde metamorphism. The lime-silicates of the non-magnesian marbles the clinopyroxene bands of the hornblende-bytownite-gneisses and the clinopyroxene-bearing amphibolite appear to be very sensitive to retrograde metamorphism. These processes have produced clinozoisite, tremolite, actinolite, prehnite, muscovite, sericite and albite. In one case prehnite was clearly later than clinozoisite. Further it was not possible to determine whether the above mentioned minerals form more than one paragenesis.

Close along the contacts of late disconformable pegmatites the synkinematic paragenesis can have been altered into pennine, epidote-clinozoisite, sericite, actinolite, prehnite. At larger distances from the dykes those minerals are also found in small quantities in the resisters. Probably they are to a large extent connected with the late pegmatites.

CHAPTER V

PEGMATITES, LEUCOCRATIC QUARTZ-DIORITES AND MUSCOVITE-BIOTITE-GRANITES

The pegmatites, leucocratic quartz-diorites and muscovite-biotite-granites can be subdivided into two main groups, depending on their shapes and structural relations to the enclosing rocks.

1⁰. Bodies of which we were able to deduce that deformation had played an important role during or immediately after their emplacement. These bodies are synkinematic.

2⁰. Pegmatites, etc. which do not show any indication of being influenced by the Hercynian deformation. They are post-kinematic.

A. PEGMATITES

a. Synkinematic pegmatites

1. *Boudinaged sills*

Sills of pegmatite, showing boudinage (fig. 39), are abundant near the boundary between mica-schists and migmatites. Elsewhere they have also frequently been observed, for instance, in the garnet-bearing biotite gneisses near Lapège (p. 131) or in a complex of migmatites between Illier and Lapège. The thickness of the boudins varies from a few centimetres to 10 m. Gneissose structure is rarely evident in these pegmatites. In several instances it was possible to establish that the longitudinal axes of the boudins parallel the fold axes in the enclosing rocks.

Many transitions have been found between pegmatites and the quartz-felspar veins in the migmatites. It was already suggested that pegmatization is one of the aspects of the migmatization (p. 124).

In general the contacts with the enclosing rocks are sharp.

2a. *Foliated unconformable pegmatites*

Such dikes were found in the quartz-dioritic gneisses close west of the cabin of Hioula. They occur in a fairly narrow zone where the foliation is very obvious. It appears as though the quartz and felspar of the pegmatites were smeared out in the direction of the foliation. This zone in the quartz-dioritic gneisses is not a mylonite zone which was formed after the Hercynian metamorphism. Biotite does not show any trace of chloritization here.

2b. *Ptygmatically folded pegmatites*

Ptygmatically folded pegmatites are, among others, present near the migmatite boundary (see fig. 40) and in the quartz-dioritic gneisses of Hioula. These pegmatites never show foliation. This might indicate that ptygmatic folding in the Trois Seigneurs massif is the result of compression in the rocks perpendicular to the foliation (H. Ramberg, 1956, p. 192) and not of differential movements in the direction of the foliation. In bodies of amphi-

Fig. 39. Boudinaged pegmatite sills in mica-schist. The handkerchief in the right hand side of the figure also covers a small boudin; étang Bleu.

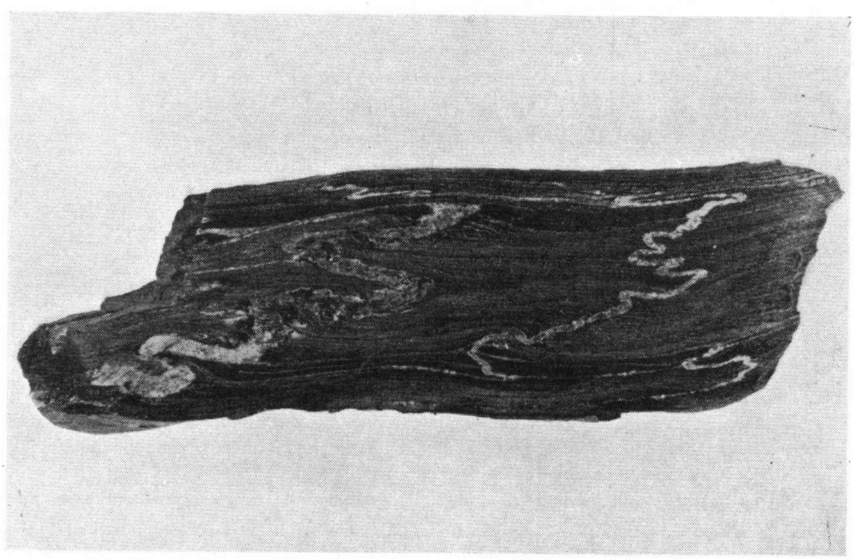


Fig. 40. Ptygmatically folded veins in mica-schist south of the étang d'Arbu. × ½.

bolite ptygmatically folded veins have also often been found. These never show such severe folding as the veins in the mica-schists and quartz-dioritic gneisses. Presumably this is an expression of the greater competency and lower plasticity of the amphibolites as compared with the schists and gneisses.

3. *Pegmatites filling spaces between boudins*

In sillimanite gneisses south of the étang d'Arbu, pegmatite bodies occur between boudins of boudinaged layers of hornblende- and biotite-bytownite-gneiss (see also H. RAMBERG, 1956, p. 195). It is probable that these pegmatites are later than the boudinaged pegmatite sills which occur so frequently in the same surroundings.

4. *Saddle reefs*

Along the road immediately west of Lapège, pegmatite concentrations have often been encountered in fold hinges of lime-silicate bands. Similar features occur in the garnet-bearing biotite-gneisses south of Lapège (fig. 15) and also opposite the lunch tree (fig. 30). In the last case it is probable that the pegmatization has continued after the termination of the Hercynian deformation. This conclusion is based on the observation that the enclosing rock along the immediate contacts of the pegmatite appears to have been recrystallized under static conditions.

5. *Folded pegmatite sills*

Folded pegmatite sills occur in many places, for instance in the mica-schists near the migmatite boundary south of the Pic de Peyroutet, in nebulitic rocks near lake Artax and also in the lime-silicate rocks south of Lapège. Their conformable character is always very striking, cross-cutting off shoots were not observed. Several times it was seen that these sills are connected with pegmatite bodies, showing boudinage.

b. Post-kinematic pegmatites

1. *Sills*

In the mica-schists pegmatite sills are strongly represented in a zone some 800 m south of the biotite isograd. The sills are not boudinaged and foliation is never evident in the rock. The result of static recrystallization appears to have been very important in the enclosing mica-schists. Muscovitization has taken place on a large scale. Near the contacts of the pegmatites sillimanite has often been found in association with muscovite. South of the pegmatite-rich zone, for example on the southern slope of the valley of the Rabat, the synkinematic character of the mica-schists has been well preserved. Nevertheless the replacing transverse muscovites still are of frequent occurrence in these surroundings. Immediately north of the pegmatite-rich zone the transverse muscovites disappear and give way to static clinochlore (see Chapter I, p. 114). Also in this part of the area the synkinematic structure of the mica-schists is still very clear. On account of the observed features in the pegmatite-rich zone it is safe to conclude that the pegmatization has taken place during the post-kinematic phase. Probably these pegmatites are much earlier than the late unconformable pegmatites (see below).

Sills which do not show boudinage, also occur in considerable quantities near the migmatite boundary. They can often be followed over hundreds of metres. It is possible that these pegmatites are early post-kinematic. More work is needed to prove it.

Parallel bands of pegmatite are often present in the quartz-diorites, for instance, near the lunch tree south of Lapège. In this locality the bands are still connected with saddle reefs (see fig. 30). Boudinage has not been observed. It is possible that these rocks were formed during the synkinematic phase or an early stage of the post-kinematic phase.

In several instances sills of pegmatite have been found in amphibolites. Close to their contacts biotitization and microclinization has taken place under static circumstances (see p. 170). The field observations showed, that actinolitization of the green hornblende in the amphibolites is not related to these sills.

2. *Diffuse pegmatites*

Felspar porphyroblasts, varying greatly in size, occur frequently in the quartz-diorites. They usually show anhedral outlines. In places, the porphyroblasts occur in great quantities, but elsewhere, though rarely, they are completely wanting. In the amphibolite-rich zone east of the lake of Artax and also in the steep east slope of the Pic de Bassibié, concentrations of felspar augen are of frequent occurrence. Such pegmatites have a rather vague form (largest diameter 1 m) and diffuse contacts.

Basic schlieren which run from the enclosing quartz-diorite right through these pegmatites consist of randomly oriented biotite crystals. In some cases there are indications that the original position and form of these small bodies have been changed as a result of rheomorphism. Therefore we may conclude that some of them are post-kinematic and pre-rheomorphic. It is however, not certain that the numerous augen in the quartz-diorites are all post-kinematic. Possibly they originated to some extent during the synkinematic phase, whilst their growth continued after the termination of the Hercynian deformation (see also GUITARD, 1955, p. 451).

3. *Basic pegmatites*

Small lenticular bodies, consisting of coarse hornblende prisms which show a random orientation, occur frequently in amphibolite and hornblende-bytownite-gneiss. Their length varies between a few centimetres and several decimetres. The bands of the enclosing rocks often bend around the lenses. The hornblende of these pegmatites mostly shows the same optical properties as the green hornblende which occurs normally in these types of resisters. Actinolitization does not seem to be related with the basic pegmatites. Therefore it is probable that they were formed before the late unconformable pegmatites of the mapped area.

4. *Unconformable dikes*

Unconformable dikes of pegmatite occur in the mica-schists, gneisses and quartz-diorites. They vary greatly in size and their course is often irregular.

Close to the contacts of these pegmatites, basic resisters are greatly altered. Biotite has been completely replaced by chlorite and prehnite, and plagioclase by sericite, clinozoisite and prehnite, green hornblende has been largely changed into actinolite. At a distance of more than 10 cm from the contacts these alterations of the primary minerals occur but rarely. The occurrence of this paragenesis in association with these dikes indicates that the temperature in the rock series was already very low during their emplacement. Therefore it is concluded that they have originated during a very late stage of the post-kinematic phase. The disconformable pegmatites are common and it is probable that the secondary alteration products which occur everywhere in the gneisses, quartz-diorites and resisters are to a large extent associated with these dikes.

The mineralogical composition of the pegmatites varies. In quartz-diorites, migmatites and other synkinematic gneisses they usually consist of potash-felspar, plagioclase, quartz, muscovite, biotite and tourmaline. The frequency of the three last-mentioned constituents is variable. Often they are not present at all. In the quartz-dioritic gneisses the pegmatites never contain muscovite, but biotite and also potash-felspar are usually present. In amphibolites there are pegmatites which only consist of plagioclase, quartz and biotite, whereas in other ones potash-felspar appears in addition to these three constituents. Muscovite has never been found. It is not yet possible to give rules for the variations in mineralogical composition of the pegmatites, but it does appear that there is a definite connection between the mineralogical composition of the pegmatites and the composition of their host-rock.

It will be clear that pegmatites were formed during different stages of the Hercynian metamorphism. In some cases it was possible to establish that pegmatization had ceased before the termination of the deformation, for example the boudinaged pegmatites. In other cases however, this process appears to have started during the synkinematic phase but continued after the termination of the deformation (see above under saddle reefs). In many places pegmatization did not take place until the last stages of the metamorphism.

B. LEUCOCRATIC QUARTZ-DIORITES AND GRANITES

a. Sills of leucocratic quartz-diorite and granite

Near the migmatite boundary sills of medium-grained leucocratic quartz-diorite and granite are of frequent occurrence. They are often boudinaged and the rock frequently shows foliation. The thickness of these bodies ranges from a few centimetres to several metres. They can often be followed over many tens or sometimes even hundreds of metres. Next to quartz and felspar these rocks contain a small quantity of mica. Sometimes biotite is present, in other instances two micas or only muscovite occur, and in many cases micas are not present at all.

Parallel bands of leucocratic quartz-diorite, granite and also pegmatite occur frequently in the quartz-diorites (see Chapter III, p. 149). We were able to make probable that a number of these rock bodies is synkinematic. Others are possibly post-kinematic, but in any case pre-rheomorphic.

b. Unconformable bodies

500 m south of the Pic de Pioulou a body, mainly consisting of leucocratic biotite-muscovite-quartz-diorite occurs. It has a length of about 200 m

and lies with it is longitudinal direction oblique to the foliation of the enclosing rocks. Many off-shoots emanate from this body and merge into the sills of leucocratic rocks which occur very frequently in these surroundings. Contacts with the enclosing gneisses are, as far as visible, transitional and occasionally sharp. There are no indications that this body has pushed aside the surrounding rocks.

Vein-like masses of a coarse-grained muscovite-granite form a continuous mesh-work in the leucocratic quartz-diorite. The granite does not appear to be later than the main rock type of the body. Several inclusions of basic resisters occur in the leucocratic quartz-diorite. Their distribution reminds that of the inclusions in the quartz-diorites which could be shown to have been rheomorphic.

	703 A
SiO_2	70.10
Al_2O_3	16.34
Fe_2O_3	1.01
FeO	1.80
MnO	0.08
MgO	0.30
CaO	2.28
NaO	5.10
K_2O	1.92
TiO_2	0.39
P_2O_5	0.07
H_2O	0.61
	99.98

Analyst: Dr C. M. DE SITTER—KOOMANS.

A chemical analysis of the leucocratic quartz-diorite was prepared. It is very similar to the analysis of the trondhjemites which are described by GOLDSCHMIDT (1921). Compared with the quartz-diorites the percentage of Na_2O is rather high and that of K_2O low. The quantity of CaO is not so small.

Two other elongated bodies of leucocratic quartz-diorite or granite with sizes of more than one hundred metres have also been found in quartz-diorite NW respectively SW of the Pic de Querquéou. Their contacts with the enclosing rocks are always transitional.

It is not possible to draw definite conclusions about the time of origin of the rock types mentioned under a and b. The boudinaged sills seem to be synkinematic. Possibly the leucocratic quartz-diorites and granites are in many cases post-kinematic but pre-rheomorphic. The body, occurring south of the Pic de Pioulou, probably originated as a result of rheomorphism in a concentration of sills of leucocratic quartz-diorite and also pegmatite.

c. Muscovite-biotite granitic gneiss

Sills of muscovite-biotite granitic gneiss occur close above the migmatite boundary south of the étang d'Arbu and near the étang Bleu. They have a thickness of several tens of metres and can be followed over large distances. The sill south of étang d'Arbu is boudinaged. The boudins have sizes of 30×150 m (see the map).

The rock has an average grain size of nearly 2 mm. In handspecimen felspar, quartz, a little biotite and muscovite can be discerned. The quantity of biotite varies, in many instances this mineral is absent. Foliation is distinct in the gneiss. Megascopically it is apparent that biotite is frequently incorporated in muscovite.

Microscopy. P o t a s h - f e l s p a r is abundant and is in the majority with regard to plagioclase. Microclinic twinning is very common. The mineral occurs either as elongated and oriented crystals of a maximum length of 3 mm or irregular small grains. In many cases the potash-felspar is slightly kaolinized. P l a g i o c l a s e (An_{15}) often shows a distinct parallel elongation, but also forms shapeless grains with irregular contacts. Occasionally the individuals are slightly sericitized and kaolinized. Potash-felspar and plagioclase are often very intimately intergrown. Q u a r t z is in irregular crystals with a size up to 2 mm. Laths of b i o t i t e are well-oriented but have strongly corroded outlines. Their average length is 0.6 mm. M u s c o v i t e occurs as separate and irregular plates showing a random orientation. It forms also vein-like aggregates lying in the direction of the foliation. The mineral replaces plagioclase, potash-felspar and biotite and is clearly later than these constituents. Fine needles of s i l l i m a n i t e or small masses of fibrolite have been found in muscovite. A p a t i t e and z i r c o n are accessories.

Origin of the granitic gneiss. NIEUWENHUYS (1956, p. 493) already emphasized the great similarity in chemical and mineralogical composition between the granitic gneiss from the Trois Seigneurs massif and the linear muscovite-biotite augengneiss of the St. Barthélemy massif, mapped and described by ZWART (1954, p. 124—150). This augengneiss appears as a continuous and conformable band of many hundreds of metres width close above the migmatite boundary. So it has the same position as the granitic gneisses from the mapped area. There is however, still an important difference between the two rock types. The foliation in the augengneisses is very pronounced, whereas linear texture is always distinct. In the authors opinion it is therefore possible that the linear augengneisses were formed during an earlier stage of the synkinematic phase than the gneissose granites. In this respect it is questionable whether the linear augengneiss of the St. Barthélemy massif are comparable with the gneissose granites based on their similar position in the rock series, and their identical mineralogical and chemical composition.

d. The massif of muscovite-granite of the Pic d'Estibat

A big body consisting mainly of muscovite-granite occurs immediately south of the col de Port in the northern part of the Trois Seigneurs massif. It lies in the mica-schists close above the migmatite boundary. Septa of mica-schists and sillimanite-gneiss occur in several places. The contacts with the enclosing rocks are mostly conformable. Dikes of pegmatite have often been found in the muscovite-granite. I have not made enough observations to draw conclusions concerning the time of origin of the body. It is possible that the granite originally is synkinematic, whilst its gneissose structure may have been lost as a result of static recrystallization. Another possibility is that this rock is early post-kinematic.

CHAPTER VI

BIOTITE-MUSCOVITE-GRANITE OF LA RUSE

A. FIELD RELATIONS

NIEUWENHUYS (1956, p. 496) has already shown that the massif of la Ruse does not consist of biotite-granodiorite as indicated on feuille Foix (1950), but of biotite-muscovite-granite. The chemical and the mineralogical composition of this rock type differ greatly from those of the intrusive biotite-granodiorite. The granite body lies in regional metamorphic mica-schists. Synkinematic andalusite was frequently found in the enclosing rocks north of the batholith. The influence of the contact metamorphism on the mica-schists has not been very important. It appears from the microscopical investigations that a slight disorientation of the micas has taken place in the direct surroundings of the massif. The synkinematic character of the andalusite, however, has not been lost. Muscovitization has hardly taken place in the contact-zone. Sillimanite has been found only along the immediate contacts.

The contacts with the enclosing rocks are generally conformable. On the east side of the massif the strike of the schistosity in the schists deviates strongly from the regional strike. Near point 1674 an important outcrop of mica-schist occurs which is completely surrounded by the granite (see the map). In this case the contact and the schistosity of the schists are horizontal.

North of the granitic body the biotite isograd in the schists bends to the north.

B. DESCRIPTION

Small specks of biotite and plates of muscovite are regularly distributed in a medium-grained felspar-quartz aggregate with an average grain size of 3 to 4 mm. Coarse crystals of potash-felspar with a maximum diameter of ¾ cm are sparsely distributed. In a marginal zone of the batholith having a width of 50 m, the rock is somewhat finer-grained than usual.

Microscopy. In this rock type similar intimate intergrowths between plagioclase and potash-felspar can be seen as in the gneissose granites, described above. P o t a s h - f e l s p a r is abundant. Microclinic twinning and microperthitic intergrowths are frequent. This mineral often shows the tendency to develop as subhedral crystals. P l a g i o c l a s e (An_{15}) is anhedral and usually has very irregular shapes. Partial alteration into sericite has been observed. M u s c o v i t e forms rather large subhedral plates. These are often fibrose along their contacts with felspar. Sometimes fibrose off shoots from the larger plates penetrate deeply into the felspar crystals. Laths of b i o t i t e are sparsely distributed. Accessories are a p a t i t e, z i r c o n and t o u r m a l i n e.

C. ORIGIN

On account of the deviation of the schistosity on the east side and "upper side" (point 1674, see the map) of the batholith, the bending of the biotite line on its north side and the occurrence of a finer-grained marginal zone which could be interpreted as a chilled margin, it is suggested that the biotite-muscovite-granite is intrusive.

Chemically (NIEUWENHUYS, 1956, p. 497) and mineralogically the biotite-muscovite-granite shows a striking similarity with the linear muscovite-biotite augen gneisses (ZWART, 1954, p. 131, 132), the granitic gneisses (p. 192) and the muscovite-granite of the Pic d'Estibat (THIEBAUT, 1956, p. 69). As a rule these rocks appear as bodies of variable sizes near the migmatite boundary. It is therefore tentatively suggested that the possible magma of the muscovite-biotite-granite has originated from a similar body which has become rheomorphic and intrusive during a late stage of the Hercynian metamorphism. If this supposition is correct it should be emphasized that the biotite-muscovite-granite magma has been formed at a relatively shallow depth in the earth's crust. In this connection the position of the granite of the Pic d'Estibat has also to be considered.

CHAPTER VII

BIOTITE-GRANODIORITE

Batholiths of biotite-granodiorite occur in many places in the Paleozoic rocks of the Pyrenees. They never penetrate the cores of the autochthonous gneiss massifs (E. RAGUIN, 1938, p. 26).

The intrusive character of the biotite-granodiorites is very pronounced according to E. RAGUIN (1938, p. 24). On the contrary G. GUITARD (1955) is of the opinion that they are of metasomatic origin. In general I think that this is improbable.

In French literature this rock type has been named for example granite carbonifère (E. RAGUIN, 1938, p. 23—26), granite hercynien (E. RAGUIN, 1946), granite circonscrit (G. GUITARD, 1955) or granite franc (J. DURAND, 1939, p. 5).

A. OCCURRENCE

Biotite-granodiorite has been encountered at three places in the mapped area. Firstly, in the southern central part a batholith of 2 × 6 km size occurs, which is called the massif of the Pic des Trois Seigneurs (see the map). The light coloured body of granodiorite can be mapped almost entirely from the aerial photographs. It is almost completely enclosed by mica-schists. West of the Port d'Ercé the granodiorite is separated from mesozoic rocks by a fault. Two other small elongated bodies of granodiorite occur more southward in the fault zone on the boundary between mesozoic limestones and the crystalline rocks of the Trois Seigneurs massif, one near les Bordes and the other between Suc and Orus. The eastern contact of the batholith of the Pic des Trois Seigneurs lies very close to the migmatite boundary, an exceptional situation in the Pyrenees (see also E. RAGUIN, 1938, p. 23, 26).

B. RELATIONSHIP TO THE ENCLOSING ROCKS

Along the west-, north- and south side of the batholith of the Pic des Trois Seigneurs the contacts are nearly vertical. East of the étang Bleu the contact plane dips to the west. In this place the schists plunge under the granodiorite. In general the schistosity of the mica-schists is lying parallel to the contact of the batholith. On its east and west side the strike of the schistosity of the enclosing rocks deviates therefore strongly from the regional strike. In detail the conformable character of the contacts is not always evident, for instance south of the Pic de Peyroutet.

Off étang Bleu the migmatite boundary bends around the eastern extremity of the batholith (see the map) and runs parallel to its contact for a distance of some kilometres.

C. MEGASCOPIC DESCRIPTION

In the outcrops the biotite-granodiorite always shows a homogeneous character. The rock is massive and medium-grained in texture. Foliation, produced by a rude orientation of the biotite plates is only distinct in the western part of the small massif of Suc-Orus. Plagioclase, quartz, biotite and potash-felspar can be discerned in the hand-specimen. Biotite occupies in general 15—20 % of the volume. Occasionally, coarser crystals of potash-felspar with a maximum size of 1 cm are present. They often enclose crystals of the three other main constituents. In the vicinity of the étang d'Arbu, hornblende occurs sparsely distributed as separate crystals or in small clusters.

In a marginal zone, some tens of metres thick, the granodiorite is more melanocratic than ordinarily. The quantity of the biotite in this contact facies is 20 to 30 %. Features which could be interpreted as a chilled margin were not observed.

The contacts of the granodiorite with the mica-schists are in general sharp, migmatic zones do not occur at all. In the enclosing rocks sills of granodiorite of 1 to 2 m thickness have sometimes been found up to a distance of 30 m from the contact. These sills are as melanocratic as the contact facies.

Xenoliths of the enclosing rocks occur in the melanocratic marginal zone of the granodiorite. They are up to some tens of metres in size. At a somewhat larger distance from the contact small inclusions of dioritic or gabbroic rocks were frequently found. In the core of the batholith such xenoliths are very rare. Therefore it is not probable that these rocks represent basic differentiation products of the magma.

The biotite-granodiorite of Bassiès generally appears to be much more leucocratic than the granodiorite of the Pic des Trois Seigneurs. The first mentioned batholith which is elongated in ENE—WSW direction probably lies much higher in the rock series than the latter.

D. MICROSCOPIC DESCRIPTION

P l a g i o c l a s e (andesine) is usually hypidiomorphic. Normal zoning occurs frequently. Oscillatory zoning has been observed several times. The number of oscillations is always quite large and never less than 10. On the other hand, the number of oscillations in the plagioclases of the quartz-dioritic gneisses is much smaller (see p. 126). The basic cores of the crystals are often partly altered into sericite and clinozoisite. Q u a r t z appears as irregular crystals showing wavy extinction. B i o t i t e has always strongly corroded outlines. Prehnite lenses may split the mica plates. Alterations into pennine and e p i d o t e have also been observed. The epidote crystals, which replace the biotite, have often attained rather large sizes and are mostly subhedral. Part of the p o t a s h - f e l s p a r shows microclinic twinning. This constituent occurs as irregular crystals lying among the other minerals and may attain a size of 1 cm. Idiomorphic inclusions of plagioclase are often present. In many instances it was observed that the potash-felspar has replaced the plagioclase, and it is safe to conclude that the former crystallized later than the plagioclase. Myrmekite is frequent. The quantity of the potash-felspar in the granodiorite is not very large. In general its percentage is close to 15. This mineral is still much less represented in the contact facies of the batholith of the Pic des Trois Seigneurs and in the small massifs of les Bordes and Suc-Orus. Accessories are z i r c o n, a p a t i t e, o r t h i t e, o r e and occasionally g r e e n h o r n b l e n d e.

In association with mylonitic zones, occurring in the granodiorite of les Bordes and also in the extreme SW part of the batholith of the Pic des

Trois Seigneurs, the rock is strongly altered. Biotite is almost completely replaced by negative pennine and the plagioclase by albite. In several instances it was seen that the potash-felspar has been entirely albitized. The albite which replaced the plagioclase is always sieved by small laths of muscovite (see also Chapter VIII). Epidote minerals do not occur in the mylonite zones. It is not possible to decide whether these alterations have taken place during the Late Hercynian period of faulting or as a result of reactivation of the pre-existing fault during the alpine orogeny.

E. PEGMATITES AND APLITES

The biotite-granodiorite carries some dykes of pegmatite and aplite. South of the Pic de Peyroutet they are more frequent than elsewhere. These rocks consist largely of potash-felspar and generally contain little quartz. Concentrations of tourmaline or of biotite and muscovite have locally been found. The pegmatites of the biotite-granodiorite have much less mica, tourmaline and quartz than those associated with the migmatite series.

The contacts of the dykes with the enclosing rocks are often sharp, but in many other cases transitional. Chilled margins have not been observed. The author presumes from the cursory observations concerning their relations to the granodiorite that the pegmatites have originated by replacement, but more work is needed to prove it.

Pegmatites belonging to the biotite-granodiorite have nowhere been found in the mica-schists. Sills or dykes of pegmatite which occur in considerable quantities near the étang Bleu or south of the étang d'Arbu appear to be associated with the migmatite series (see Chapter V).

F. LAMPROPHYRES

a. *Microdiorite.* South of étang d'Arbu a dyke of micro-diorite with a thickness of about 2 m occurs in biotite-granodiorite. It strikes in an east—west direction and can be followed over a distance of several hundreds of metres. The rock is fine-grained and massive in texture. Along the contacts of the dyke a slight foliation is apparent. Felspar and flakes of biotite can be seen megascopically. Under the microscope plagioclase averaging 0.5 mm in size appears as subhedral crystals. Zoning is often distinct, the basic cores (andesine) are often sericitized and kaolinized. The more acid rims of the crystals consist of albite. Biotite is somewhat less represented than plagioclase and forms plates which often show strongly corroded outlines. Green hornblende is less frequent than the other two constituents. Quartz is present in small amounts. In the contact facies of the rock the crystals of plagioclase,, biotite and hornblende show a rude orientation.

b. *Barkevikite-bearing lamprophyre.* Another dyke which is completely different from the microdiorite has been found 1½ km west of the Pic de Barre. The rock has a greyish black colour and is very fine-grained and massive. Phenocrysts of ferro-magnesian minerals occur sparsely distributed. In thin section euhedral phenocrysts of titaniferous augite with a size of several millimetres can be seen in a fine-grained groundmass of amphibole and plagioclase. Pseudomorphs, consisting of calcite and serpentine are sparsely distributed. They are of the same size as the augite crystals and often show euhedral outlines (bipyramidal prismatic). Relics of the original mineral were not found. The groundmass is composed of needles or prisms of barkevikitic hornblende ($n\gamma/c$ appr. 6°) and fairly basic plagioclase (labradiorite?). In some places the needles are well-oriented, elsewhere they do not show preferred orientation.

G. THE CONTACT AUREOLE

Field observations show that the mica-schists have been recrystallized statically, up to a distance of at most 100 m from the contact. In this zone the grain size of the rocks is larger than elsewhere and in general foliation is indistinct or absent. The micas of these rocks always show a random orientation. In fact these contact rocks should no longer be called mica-schists, but biotite-muscovite rocks or sillimanite-biotite-muscovite rocks. Sillimanite occurs in considerable quantities and is often megascopically visible. The effect of the static recrystallization on the rocks has not been the same everywhere. Bands of massive (sillimanite-) biotite-muscovite rocks alternate with others in which foliation is still discernable.

In the contact zone sillimanite is much more abundant than in the regional metamorphic sillimanite-schists which occur near the migmatite boundary. Therefore it may be concluded that the sillimanite in this zone originated largely as a result of contact metamorphism. Sillimanite mostly appears to have been originated at the expense of biotite, but is often also incorporated in muscovite. North of the batholith, andalusite appears for the first time outside the zone of sillimanite-biotite-muscovite rocks. At a distance of about 150 m from the contact this mineral is mostly static. Further to the north the quantity of synkinematic andalusite increases more and more. It is probable that the static andalusite, occurring immediately outside the zone of unfoliated contact rocks, was also formed as a result of contact metamorphism.

The map shows that there is no hiatus in the sequence of the metamorphic series north and south of the granodiorite body. It is possible to join the schists on the southern contact with those which are present along the northern contact, when the contact metamorphism of the granodiorite is subtracted. This could indicate that the intruding body has largely pushed aside the enclosing rocks.

The contacts of the granodiorite are not parallel to the metamorphic boundaries which were formed during the Hercynian metamorphism. The eastern extremity of the batholith is very close to the migmatite boundary and the sillimanite zone. To the west the distance between the southern contact and the migmatite boundary increases gradually. The western contact is lying approximately on the border between the sillimanite- and andalusite zone or perhaps even in the andalusite zone.

H. CHEMICAL COMPOSITION OF THE BIOTITE-GRANODIORITE

Three new chemical analyses of biotite-granodiorite have been made from different localities in the mapped area. In table III the analyses which were published by NIEUWENHUYS (1956) are also given. The 5 analyses resemble each other. The percentage of CaO is usually fairly high. The quantity of Na_2O is rather constant. The percentage of K_2O in the granodiorite of the Pic des Trois Seigneurs appears to be somewhat higher than in the analyses of the small massifs of Orus-Sentenac and les Bordes. Evidently this difference is already expressed in the mineralogical composition of the rocks in the different occurrences. It has been established by microscopical observations that potash-felspar is less represented in the small massifs than in the batholith of the Pic des Trois Seigneurs.

Two new analyses of the granodiorite of Bassiès have also been made in the Laboratory of Leyden. Differences as compared with the analyses from the Trois Seigneurs massif are distinct. The percentages of SiO_2 and K_2O are somewhat higher, but those of MgO, FeO and Fe_2O_3 are lower. The percentage of CaO is not very different. Chemically the granodiorite of Bassiès is less basic than the granodiorite of the Pic des Trois Seigneurs. The first-mentioned batholith lies much higher in the paleozoic rock series than the latter. Probably the difference in chemical composition is a result of magmatic differentiation which had taken place in the original magma of the granodiorite of Bassiès. Evidently the quantity of CaO hardly changed during this process.

TABLE III

CHEMICAL ANALYSES OF BIOTITE-GRANODIORITE

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
SiO_2	63.82	62.42	64.25	65.75	62.50	65.75	68.52	63.60	60.48
Al_2O_3	16.59	16.84	16.30	16.81	17.20	16.68	14.92	16.20	16.22
Fe_2O_3	1.48	1.64	1.51	0.57	1.09	0.65	0.96	1.09	0.51
FeO	3.66	4.14	3.07	3.44	3.66	2.91	2.79	3.84	4.08
MnO	0.10	0.13	0.10	0.03	0.18	0.07	0.11	0.05	0.06
MgO	1.39	2.24	2.72	2.02	2.56	0.99	1.25	2.29	2.93
CaO	5.36	5.32	4.08	3.63	4.69	4.50	4.12	4.33	4.42
Na_2O	3.00	3.52	3.14	3.30	3.08	3.32	3.40	3.16	2.77
K_2O	2.16	1.96	3.30	2.96	2.70	3.30	3.12	3.42	3.24
TiO_2	0.79	0.72	0.64	0.48	0.73	0.76	0.54	0.72	0.88
P_2O_5	0.24	0.20	0.18	0.03	0.19	0.14	0.06	0.24	0.32
CO_2	—	—	—	—	—	—	—	—	1.47
H_2O	1.60	0.91	0.97	1.18	1.06	0.76	0.73	1.22	2.54
	100.19	100.04	100.26	100.20	99.64	99.83	100.52	100.16	99.92

a. Massif of Suc-Orus.
b. „ „ Les Bordes (NIEUWENHUYS, 1956).
c. „ „ the Pic des Trois Seigneurs (NIEUWENHUYS, 1956).
d. „ „ „ „ „ „ „ 1½ km NW of the Pic de Barre.
e. „ „ „ „ „ „ „ south of the étang d'Arbu.
f. „ „ „ Bassiès, contact facies.
g. „ „ „ „ .
h. Biotite-granodiorite of Lacourt } weathered specimens.
i. „ „ „ Foix }

Analyst: Dr. C. M. DE SITTER—KOOMANS.

A comparison with the chemical analyses of the autochthonous quartz-diorites or gneisses gives the following results.

1°. The chemical composition of the autochthonous quartz-diorites and gneisses is more variable than that of the biotite-granodiorites.

2°. In general the autochthonous granitic rocks have a much lower percentage of CaO than the biotite-granodiorites.

3°. In the quartz-diorites and gneisses the percentages of iron and magnesian are obviously higher than in the granodiorite of Bassiès but as high as in the granodiorite of the Pic des Trois Seigneurs, of Lacourt and of Foix.

In this respect the latter occupy a transitional position between the autochthonous rocks and the granodiorite of Bassiès.

4°. The Na-K-ratio is much higher in the quartz-diorites and gneisses than in the biotite-granodiorites.

I. SHAPE OF THE GRANODIORITE BODIES OF THE PIC DES TROIS SEIGNEURS AND OF BASSIES

The batholith of the Pic des Trois Seigneurs attains its largest dimension in the highest parts of the mapped area. Off the Pic des Trois Seigneurs the width of the body in north—south direction is well over 2 km (see the map). Eastward the mountains become lower whilst the width of the granodiorite body decreases. This might indicate that the batholith narrows downward.

ZWART (1954, p. 210) has made probable that before the late Hercynian period of faulting the granodiorite of the Pic des Trois Seigneurs was connected with the batholith of Bassiès. It should be noted that this body is enclosed by non-metamorphic upper Ordovician rocks and it cuts even graptolite-bearing Silurian near Auzat (ALLAART, 1954). The granodiorite from the mapped area is enclosed by Cambro-Ordovician rocks. Furthermore, DE SITTER (1954) and ZWART (1954) have proved that the Trois Seigneurs massif has been tilted to the north. According to these authors the displacement in vertical direction of the southern border of this massif with regard to the axial zone along the North Pyrenean fault is about 6 km. Therefore it is very probably that the contacts of the granodiorite of Bassiès lie much higher in the rocks series than those of the batholith of the Pic des Trois Seigneurs. The dimensions of the former are considerable larger than those of the latter. Possibly this is an indication that the whole original granodiorite body narrowed downward. This reasoning is very attractive, but it only applies if we assume that the just-mentioned body originally had not an irregular shape. This is difficult to prove, but near the contact with the Mesozoic rocks the width of the Bassiès batholith does not show any trace of narrowing in ENE direction.

K. CONCLUSIONS

The intrusive character of the granodiorite of the Pic des Trois Seigneurs is striking, mainly by evidence of pushing aside of the enclosing rocks. This is especially clear on the east- and west side of the batholith, where the strike of the schistosity in the schists deviates strongly from the regional direction of schistosity. The bending of the migmatite boundary near the étang Bleu is probably also a result of the shouldering aside by the intruding magma.

The granodiorite body is lying obliquely to the metamorphic isograds, which have been formed as a result of the Hercynian metamorphism. This is already clear from the course of the migmatite boundary with regard to the southern contact of the batholith.

It is difficult to determine exactly when the intrusion has taken place. The presence of the zone of unfoliated biotite-muscovite-sillimanite rocks around the batholith may indicate that this event has happened during an advanced stage of the post-kinematic phase of the Hercynian metamorphism or still later.

The origin of the biotite-granodiorite magma presents another problem. RAGUIN (1938, p. 26) has already stated that in the Pyrenees the biotite-granodiorites never penetrate the autochthonous gneiss massifs. This might indicate that the magma has not originated at a much larger depth in the earth crust than the gneisses. Furthermore, the batholiths appear in Ordovician, Devonian and Carboniferous rocks. On the other hand the autochthonous granitic rocks are lying in ordovician or still older rocks. The gneiss massifs thus occur independently of the granodiorites, but the latter generally lie much higher in the Paleozoic rock series than the former. Therefore it is tempting to assume that the granodiorite magma has originated at the expense of the quartz-diorites and gneisses which have become intrusive. The suppositions which were made in the last paragraph give rise to suggest that the connection of the granodiorite body of the Pic des Trois Seigneurs with the autochthonous rocks has already more or less been lost.

CHAPTER VIII

CHLORITE-ALBITE ROCKS AND ASSOCIATED CHLORITITES

A. CHLORITE-ALBITE ROCKS AND ASSOCIATED ROCK TYPES IN GNEISSES AND QUARTZ-DIORITES

a. Occurrence

Bodies of chlorite-albite rock occur in many places in the gneisses and quartz-diorites of the Trois Seigneurs massif. With their light colour, due to weathering, they stand clearly out in the brown weathered enclosing rocks. Small bodies of chloritite occur only in the albite-rich rocks.

Outside the mapped area, for instance north of the étang de Peyregrand chlorite-albite rocks have also been found in the gneiss d'Aston.

In the St-Barthélemy massif, along the road close NE of Cazenave, biotite-gneisses occur which enclose a body of chlorite-albite rock of about 10 m in diameter. The rock shows the same appearance as the biotite-gneiss, but it does not contain quartz, whereas chlorite replaces the biotite. The texture of the pre-existing rock has been very well preserved.

b. Field characteristics

The shape of the bodies is equidimensional, elongated or irregular. Their sizes vary mostly between 10 and 100 m. Two elongated bodies with a length of more than half a kilometre have been mapped. The contacts with the enclosing rocks are always sharp.

The observations showed that the texture of the pre-existing rocks has been well preserved in the chlorite-albite rocks. This is most obvious in an elongated body which occurs at about 1 km SW of the Pic de Pioulou. Its western part is enclosed by sillimanite-gneisses. Eastward it cuts the boundary between the sillimanite-gneisses and quartz-diorites (see the detailed map). In the western part of the body the rock is built up of chlorite-albite-gneiss with a migmatitic structure. Narrow bands which are composed of chlorite alternate regularly with others consisting of albite. In the outcrop the gneiss has the same appearance as the sillimanite-gneisses. For example, boudinage is still recognizable in the albitic bands. Sills of pegmatite, consisting of albite and little potash-felspar occur frequently and in many cases they are also distinctly boudinaged. Conformable lenses of chloritite, showing boudinage, have also been found several times. They are mostly half a metre thick. Undoubtedly these lenses have originated at the expense of basic resisters, for instance amphibolites, which have completely been chloritized.

A sill of leucocratic chlorite-muscovite-albite-gneiss, having a thickness of 10 m and a length of 100 m, occurs in the SW part of the chlorite-albite gneiss body. Quartz is not present in this rock. The leucocratic gneiss has the same position and appearance as other leucocratic biotite-muscovite-gneiss bands which occur frequently in the sillimanite-gneisses in these surroundings.

More to the NE the body of chlorite-albite rock runs across the boundary between the sillimanite-gneisses and quartz-diorites. Off this boundary the migmatitic chlorite-albite-gneisses change gradually into massive chlorite-albite rocks. In this respect the same features can be seen as on the boundary between the migmatites and quartz-diorites outside the body.

The body of chlorite-albite-gneiss lies mainly on the south slope of the crest of the Trois Seigneurs massif. Close to its NW contact many conformable quartz lenses occur in the gneiss. In the enclosing sillimanite-gneisses many unconformable quartz veins have been found. These quartz concentrations were observed only near the upper contact of the body.

200 m north of point 1555 a body of chlorite-albite rock occurs in quartz-diorite. In this locality the rock shows a massive texture. The quantity of chlorite is approximately as large as the quantity of biotite in the enclosing rocks. The grain sizes of both rock types are equal. Small inclusions of basic resisters have frequently been observed in the quartz-diorite. In the albite-rich rock small inclusions were also found. They consist almost completely of chlorite. Banding is often still clear. Their distribution and shape are the same as the distribution and shape of the inclusions in the enclosing quartz-diorite. Relics of quartz-diorite are frequently present in the albite-rich rock.

Complicated flow structures, preserved from the pre-existing nebulite, were observed in a body of chlorite-albite rock occurring along the southern border of the lake of Artax. Locally, the rock still contains quartz. A large inclusion of hornblende-bytownite-gneiss runs from the enclosing rocks into the albite-rich rock. Inside the body the resister has almost completely been changed into a chloritite.

In other localities unconformable pegmatites have also been found in the chlorite-albite rocks. They never contain quartz and only a little potash-felspar. Several times the dykes continue into the enclosing rocks. Outside the bodies of chlorite-albite rock these pegmatites always contain quartz.

At about 1700 m SSW of the Pic de Pioulou, a boudinaged layer of chloritite occurs in chlorite-albite rock. In the cores of the boudins marble is always present. Therefore it is certain that most of the chloritites have originated at the expense of basic resisters.

c. Microscopical description

In the thin sections of the chlorite-albite rocks occurring in the quartz-diorites a mosaic of xenomorphic albite grains with an average grain size of 2 mm can be seen. The albite crystals are largely sieved by small laths of muscovite, which have a length of 0.1 to 0.2 mm. Often the mica-crystals are only present in the core of their host, whereas the rims are free of muscovite. The albite is always slightly kaolinized. Irregular crystals of chess-board albite which contain relics of potash-felspar, have frequently been found.

Clinochlore or pennine form individuals of 1 to 2 mm size. They are irregularly shaped, and rarely contain relics of biotite. Fine-grained aggregates of chlorite occur interstitially between the crystals of albite. They consist of small rosettes, which show radial extinction and average 0.2 mm in size. Muscovite showing the same relations as in the quartz-diorites forms irregular plates, several millimetres in size.

Pseudomorphs after cordierite have been observed several times. They consist mainly of sericite. Along the contacts of the sericite masses intimate intergrowths of clinochlore or pennine with muscovite can be seen. The cleavages of the different individuals always lie parallel. This structure is identical with that of the muscovite-phlogopite intergrowths of the quartz-diorites, which occur in association with cordierite.

Ore, rutile, anatase, leucoxene and titanite are accessories. In most cases the last mineral has been almost completely changed into leucoxene.

The results of cataclasis are generally very distinct in the chlorite-albite rocks. The twin lamellae of albite are often bent or even folded. Muscovite crystals are frequently strongly deformed.

The chloritites usually consist of an aggregate of chlorite rosettes which show radial extinction. Their sizes vary between 0.1 and 0.5 mm. Three variations of chlorite occur: clinochlore, positive pennine and negative pennine. They are often intimately intergrown. Patches consisting of a mosaic of albite grains have several times been observed in the chloritites. Relics of earlier melanocratic constituents have not been found.

On the rock step of the glacial cirque WNW of the lake of Artax some inclusions of hornblende- and biotite-bytownite-gneiss occur in a body of chlorite-albite rock. They still have partially preserved their original character. In one thin section only plagioclase has been completely sericitized, but hornblende and biotite are entirely fresh. In a thin section of an inclusion of biotite-bytownite-gneiss the biotite has almost completely been changed into a light brown chlorite, rutile and ore; the plagioclase has been muscovitized. It is probable that the chloritization of the biotite is related to the formation of the surrounding chlorite-albite rock. The sericitization of the plagioclase, however, may just as well be the result of retrograde processes of the Hercynian metamorphism.

B. CHLORITE-ALBITE ROCK IN THE MICA-SCHISTS

SE of Trabiët, 1440 m north of the contact of the biotite-granodiorite approximately 380 m south of the biotite isograd leucocratic schists are exposed which consist of albite, chlorite and some muscovite. At first glance under the microscope there seems to be no difference compared with a normal biotite-muscovite-schist, but a closer inspection shows that albite is present instead of quartz. Apparently the chlorite has been formed at the expense of biotite. Small relics of the brown mica occur frequently in the chlorite. The original structure of the schist has been completely preserved. Originally it was a normal quartz-rich biotite-muscovite-schist, but the quartz has been entirely albitized.

C. CHLORITE-ALBITE ROCK IN THE BIOTITE-GRANODIORITE OF THE PIC DES TROIS SEIGNEURS

a. Chlorite-albite rock

At a distance of 1300 m west of the Pic de Barre a body of chlorite-albite rock occurs in the biotite-granodiorite. It has a diameter of at least 350 m. In hand-specimen albite and chlorite can be discerned, but quartz is not visible. The rock has a massive texture.

The body of chlorite-albite rock is exposed on a slope which dips to the SW (see the map). Close to its upper contact a large quartz lense occurs.

Near this lense a considerable amount of quartz veins is present in the enclosing rock.

In thin section an aggregate mainly consisting of euhedral albite crystals can be observed. Irregular crystals of potash-felspar which include small individuals of albite have several times been found. Myrmekite is not present at all. The potash-felspar individuals have been partly or completely altered into chess-board albite. In this albite, replacement veinlets of potash-felspar are of frequent occurrence. They show optic continuity with adjacent crystals of potash-felspar. Plates of chlorite, 0.5 to 1 mm in size, occur more than once and are always embedded in potash-felspar. Aggregates of chlorite occur interstitially between the grains of felspar and they consist of small rosettes in which pennine and another variety of chlorite (with a very low birefringence, unaxial positive) are intimately intergrown. Negative pennine appears in veinlets which cut through the rock in different directions. Anatase and leucoxene are accessories and occur always in association with the chlorite. Titanite is absent.

Once an elongated mass with euhedral outlines was observed, consisting of a fine-grained aggregate of chlorite and little sericite. Presumably this is a pseudomorph after hornblende.

b. Epidote-bearing chlorite-albite-rock

In a part of the body of chlorite-albite rock, epidote is present in considerable amounts. It is already clear in the hand-specimen that this mineral is always embedded in the chlorite.

Microscopy. Albite is the main constituent. It shows subhedral to euhedral outlines and has an average size of 1½ mm. The twin lamellae of the albite are often bent as a result of cataclasis. Small muscovite laths do not occur in the albite. Crystals of microcline averaging 2 mm in size are often subhedral. They are always slightly kaolinized. The potash-felspar is never albitized. Chlorite (positive and negative pennine) occasionally appears as elongated individuals of 0.5 to 1 mm size but mostly in aggregates which consist of small rosettes (see above) of 0.1 mm diameter. Relics of biotite have never been observed. In contact with these aggregates the albite always shows euhedral outlines. The chlorite masses are often partly replaced by albite.

Epidote is in the form of euhedral prisms and usually occurs in the aggregates of chlorite. In several instances parts of epidote crystals are intimately intergrown with albite. The latter mineral penetrate the epidote along its fracture and cleavage planes. Titanite is always associated with chlorite.

In the biotite-granodiorite epidotization of biotite is not uncommon (see p. 197), this process does not appear to be related with the chlorite-albite rocks. Therefore it is probable that the epidote occurring in the latter rock type originated as a result of retrograde processes immediately after the intrusion of the granodiorite. During the formation of the chlorite-albite rock the mineral may have been recrystallized and acquired an euhedral shape.

c. Chemical composition

From the chlorite-albite rock body in the biotite-granodiorite two chemical analyses have been made (see table IV a and b). In this table two other chemical analyses of biotite-granodiorite are also given (c and d). The differences in chemical composition between the two rock types are striking. Anticipating the conclusions which will be drawn at the end of this chapter it is stated that the addition of sodium has been rather important in the chlorite-albite rocks.

TABLE IV

	a	b	c	d
	Chlorite-albite rock	Epidote-bearing chlorite-albite rock	Biotite-granodiorite	Biotite-granodiorite
SiO_2	54.80	57.15	65.75	64.25
TiO_2	0.77	0.53	0.48	0.64
P_2O_5	0.10	0.05	0.03	0.18
Al_2O_3	20.50	18.52	16.81	16.30
Fe_2O_3	0.10	2.26	0.57	1.51
FeO	5.57	3.01	3.44	3.07
MnO	0.03	0.03	0.03	0.10
MgO	2.40	1.82	2.02	2.72
CaO	2.58	3.71	3.63	4.08
Na_2O	9.08	8.50	3.30	3.14
K_2O	1.76	3.00	2.96	3.30
H_2O+	2.81	1.81	1.18	0.97
	100.50	100.39	100.20	100.26

As quartz is mostly absent in the chlorite-albite rocks, it is likely that the sodium has largely been used for the formation of albite at the expense of quartz. For this reaction aluminium is also needed. The high percentages of Al_2O_3 in the analyses a and b may indicate that addition of Al has indeed taken place. During the replacement of quartz by albite the excess SiO_2 must have been removed. This is also evident in the chemical analyses. The occurrence of concentrations of quartz veins at the contacts of some bodies of chlorite-albite rock (p. 204, 205) may be another argument in favour of this conclusion.

From the microscopical investigations it appeared that: 1° epidote minerals are generally not present, 2° anatase and leucoxene occur instead of titanite, 3° relics of basic plagioclase are absent. Therefore it is tempting to conclude that a process of decalcification has taken place during the formation of these rocks. However, the percentage of CaO in the analysis of the chlorite-albite rock without epidote (a) is much higher than might be expected from the microscopical investigations.

D. ALBITIZATION AND CHLORITIZATION IN ASSOCIATION WITH FAULTS

Albitization and chloritization have also taken place in nebulites and quartz-diorites which occur close to the Cap de las Costes fault. In these rocks, plagioclase is completely albitized and sieved by the well-known small muscovite laths. Biotite is almost entirely changed into negative pennine. Aggregates of chlorite rosettes, as described above have not been found. Quartz is always present in considerable quantities. Rutile (in pennine), leucoxene and anatase are accessories. Epidote minerals are absent.

Crush zones of several metres width are of frequent occurrence in the granodiorite of les Bordes. In parts of these zones in which the influence of crushing has not been so strong, it can be seen that biotite has been almost completely altered into negative pennine, and plagioclase into albite.

Small muscovite laths and sericite occur in the albite. Microcline does not usually show any trace of albitization and quartz is still present. In one case the microcline in the rock is completely replaced by chessboard albite. Myrmekite was often observed at the contacts of the chessboard albite and the albite which has been originated at the expense of plagioclase.

It will be clear that in the quartz-bearing chlorite-albite-rocks which occur in association with faults the chlorite and albite only form pseudomorphs after pre-existing minerals. This is in contrast with the chlorite-albite rocks in which a considerable quantity of the chlorite and albite can be considered as newly formed.

In general, epidote or other Ca-bearing minerals do not occur in either rock type. On the contrary epidote or clinozoisite have as a rule originated as a result of retrograde metamorphism in the biotite-granodiorite and also in gneisses and quartz-diorites.

E. CONCLUSIONS

The most important conclusion is, that the chlorite-albite rocks were produced by sodium metasomatism which has taken place under hydrothermal conditions. This conclusion is based on field observations and could be affirmed by microscopical investigation. In the field it could be established that the textures of the pre-existing rocks are mostly very well preserved during these processes (see under field characteristics). The mineralogical composition of the pre-existing rocks has however, changed completely. The catazonal paragenesis is almost entirely replaced by albite and chlorite.

On a microscopical scale too, many relic structures of the pre-existing rocks are still evident. It also becomes clear however, from the microscopical observations that as a result of these processes new structures have originated whereas old structures have disappeared:

a) It is probable that albite has grown further at the expense of other minerals from old cores of pre-existing plagioclase crystals (p. 204). b) Chlorite often forms aggregates, which occur interstitially to the crystals of albite. It is not likely that all these aggregates are pseudomorphs after biotite. c) It appeared from several observations that potash-felspar has been redistributed. d) In the chlorite-albite rock occurring in the biotite-granodiorite of the Pic des Trois Seigneurs, myrmekite is no longer present, although potash-felspar is still rather frequent. e) The euhedral shape of the albite inclusions in the microcline crystals of the chlorite-albite rock, occurring east of the Pic de Barre, is much less distinct than that of the plagioclase inclusions, which occur in the microcline of the biotite-granodiorite.

It is not yet possible to establish the time of origin of the chlorite-albite rocks and also their connection with the processes of metamorphism, faulting and orogenesis, which successively have been active in the Trois Seigneurs massif. In the author's opinion these rocks are related with the late hercynian period of faulting or with the alpine orogeny. More work is however, needed to prove one of these suppositions.

CHAPTER IX

GEOLOGICAL SETTING AND EMPLACEMENT OF THE TROIS SEIGNEURS MASSIF

A. BOUNDARIES OF THE TROIS SEIGNEURS MASSIF

a. Abnormal contacts

The Trois Seigneurs massif is only partly bounded by faults (CASTERAS, 1933). Near Massat, where the Trois Seigneurs massif comes in contact with the Arize massif, the existence of a fault is already clear on the map. The schists are strongly brecciated up to a distance of at least 100 m from the contact. Eastward the fault disappears under quarternary deposits.

Another fault can be mapped along the southern contact of the area between Orus and the Col d'Eret. East and west of this col an important mylonite zone occurs. Up to a distance of 200 m from the contact with the Mesozoic rocks, the biotite in the mica-schists has completely been chloritized. Further eastward the fault zone is badly exposed, but its presence is shown by the occurrence of the two small elongated massifs of biotite-granodiorite along the border of the mapped area. Undoubtedly these fragments have been torn off the batholith of the Pic des Trois Seigneurs during the formation of the fault. The body of Suc-Orus has been displaced over a distance of at least 8 km in horizontal direction. This amount is somewhat greater than the estimate by ZWART (1954, pp. 120, 121) of the displacement of the Trois Seigneurs massif with regard to the axial zone, during the late Hercynian period of faulting. Possibly, the contact between the fault zone and the Mesozoic rocks represents an unconformity.

Mica-schists are still present along the western contact of the small biotite-granodiorite massif or Sentenac-Orus. In SE direction the schists change gradually into sillimanite-gneisses and these on their turn into quartz-diorites. This is the normal succession which always appears near the migmatite boundary elsewhere in the mapped area. Quartz-diorites and nebulites occur exclusively to the north of the schists and the granodiorite. Therefore it is concluded that a fault, running in east—west direction is present along the northern contact of the massif of Sentenac-Orus. The fault zone itself can not be observed because of lack of exposures.

Several times mylonite zones, which strike in WNW—ESE direction have been observed in the small massif of les Bordes.

b. Normal contacts

Along the NE side of the Trois Seigneurs massif between Chervidal and Capoulet, the contacts with the mesozoic rocks are usually vertical. In several places mylonitic rocks have been observed in the quartz-diorites and gneisses close along the contacts. Nevertheless it is not probable that a fault is present (see also CASTERAS, 1933). It is more likely that the mylonitic rocks have been formed as a result of deformation during the alpine folding, when the mesozoic limestones of the basin of Tarascon were pressed against the borders of the Trois Seigneurs massif.

Between Sentenac and Miglos on the south side of the mapped area the boundaries with the mesozoic rocks are also vertical. According to CASTERAS the contact is normal. The existence of an important fault between the Trois Seigneurs massif and the axial zone is however, certain (DE SITTER, 1954). Probably the fault zone is largely covered with mesozoic sediments, occurring south of the mapped area.

B. THE CAP DE LAS COSTES FAULT

In the NE part of the Trois Seigneurs massif a fault occurs which strikes in NNW—SSE direction, dipping steeply to the SSW. On the south slope of the valley of the Rabat this fault cannot be followed because of lack of exposures; west of Eychenne it lies approximately in the schistosity of the schists. The shifting of the migmatite boundary at both sides of the fault is considerable. It cannot be decided if the displacement has mainly taken place in vertical or in horizontal direction. Possibly the block lying north of the fault has also been tilted to the NW with regard to the other part of the Trois Seigneurs massif. By this tilting the small thickness of the micaschist zone near the Pic d'Estibat may be explained and likewise the bending of the schistosity along the south side of the fault.

C. THE EMPLACEMENT OF THE TROIS SEIGNEURS MASSIF

According to DE SITTER (1954, p. 289) the Trois Seigneurs massif has been elevated in relation to the axial zone during the late Hercynian period of faulting. At the same time the massif should have been tilted to the NW. This becomes also evident from examination of the geological map. The rocks which have lain the deepest in the earth crust are exposed in the SE part of the mapped area. Going in NW direction, there is a continuous succession of rock boundaries which are lying higher in the rock series, recurrences do not occur.

During the Late Hercynian period of faulting the three satellite massifs reacted as rigid blocks between which rather wide zones of movement were present. After the termination of the fault movements these zones apparently developed as basins in which mesozoic sediments were deposited. The Paleozoic fault zones have been covered with these rocks and are in many cases no more observable. It seems that during the alpine orogeny the basement of these basins has been highly compressed together with their Mesozoic content. Probably the three massifs have been displaced to the south by the orogenic pressure, while the intermediate mesozoic rocks were folded.

SUMMARY

In the introduction the criteria are mentioned which enable us to distinguish the products of the synkinematic and post-kinematic phases of the Hercynian metamorphism. A short characteristic has been given of the Silurian and Cambro-Ordovician rocks.

The mica-schists, discussed in Chapter I, are exposed in the southeastern, central and northern parts of the mapped area. The grade of metamorphism increases from north to south in this rock-series. A biotite-, an andalusite- and a sillimanite zone can be distinguished. The biotite- and andalusite zones originated during the synkinematic phase. However, the sillimanite of the mica-schists is thought to be post-kinematic. There are indications that the rocks of the sillimanite zone have undergone high-grade metamorphism. In the low-grade biotite-muscovite-schists a marble layer occurs with biotite-gneiss bands, containing fairly basic plagioclase.

Three varieties of synkinematic gneiss are distinguished: A) Sillimanite-gneisses (migmatites), B) quartz-dioritic gneisses and C) homogeneous biotite-gneisses. The migmatites predominate in a 200 m thick zone which is located structurally below the mica-schists. The migmatization (both lit-par-lit replacement and metamorphic differentiation probably were involved) appears to be late- to post-kinematic. Nearly all the sillimanite, however, is post-kinematic. The quartz-dioritic gneisses are supposed to have been formed by a selective sodium metasomatism of lime-bearing pelites. The biotite-gneisses possibly originated from semipelitic or pelitic rocks by sodium metasomatism.

The quartz-diorites which occur structurally below the zone of migmatites, mentioned above, occupy most of the area in the north-eastern and south-eastern parts of the region investigated. In most cases it was clear that these rocks were formed by rheomorphism at the expense of migmatites. On the other hand, static recrystallization of homogeneous biotite-gneisses may also result in the formation of quartz-diorites. The field observations show that rheomorphism took place on a regional scale in the Trois Seigneurs massif. Nowhere do the quartz-diorites break through the sillimanite-gneiss zone, which forms a continuous envelope around these rocks. Numerous relics of the pre-existing rock series are still recognizable in the autochthonous quartz-diorites.

The resisters (Chapter IV) occur as conformable layers or lenses in the synkinematic gneisses. These lenses and layers have been broken into many pieces, due to the flow movements in the rheomorphic quartz-diorites. A series of rock types of sedimentary origin (part I) could be distinguisbed: magnesian and non-magnesian marbles and lime-silicate rocks, hornblende and biotite-bytownite-gneisses (presumably original marls) and quartzites. They may be intercalated, and usually show a typical sedimentary banding. Transitions between the three different types have been observed. Another group of resisters (part II) show characteristics which indicate that they are of igneous origin. The quartz-gabbros (part III) probably originated at the expense of amphibolites through an extreme static recrystallization.

In the resisters a synkinematic paragenesis can be distinguished which can be placed in the amphibolite facies. The following minerals: diopside, clinopyroxene, grossularite, wollastonite, forsterite, spinel, calcic plagioclase and green hornblende characterize this paragenesis. Furthermore a high-grade post-kinematic association is present which contains, among others: cummingtonite, light green amphibole, pargasite, cordierite (?), anthophyllite (?), and bytownite. During the post-kinematic phase the green hornblende of the hornblende-bytownite-gneisses apparently remained stable as did the clinopyroxene, grossularite and basic plagioclase of the lime-silicate rocks. In association with late cross-cutting pegmatites a low-grade paragenesis occurs: sericite, pennine, epidote, clinozoisite, prehnite, actinolite and albite. It was not possible to establish, whether the tremolite, epidote and clinozoisite of the lime-silicate rocks originated in association with pegmatites, or as a result of the cooling in the rock series during the latest stages of the metamorphism. In general the resisters probably underwent an isochemical metamorphism.

Sills or cross-cutting dykes of pegmatite and leucocratic granitic rocks (Chapter V) are of frequent occurrence in the gneisses of the Trois Seigneurs massif. They originated during many different stages of the Hercynian metamorphism. In the quartz-diorites the early sills reacted as plastic bodies during the stage of rheomorphism and preserved their original parallel position. The muscovite-granite of the Pic d'Estibat is located close above the migmatite boundary.

The biotite-muscovite granite of la Ruse (Chapter VI) is possibly intrusive and perhaps originated at the expense of a concentration of pegmatites and leucocratic granites which, as a rule, occur near the migmatite boundary.

The biotite-granodiorite of the Pic des Trois Seigneurs is described in Chapter VII. Its intrusive character is clear, mainly from evidence of shouldering aside the enclosing rocks. It is suggested that the original magma of the granodiorite originated at the expense of autochthonous gneisses and quartz-diorites which have become intrusive. There are indications that the granodiorite body narrows downward and that the connection with the autochthonous rocks has more or less been lost.

Bodies of chlorite-albite rock (Chapter VIII) occur in many places in the gneisses and quartz-diorites of the mapped area, but also in the biotite-granodiorite of the Pic des Trois Seigneurs, and even in the mica-schists. It could be proved that these rocks were formed through a strong sodium metasomatism under hydrothermal conditions. Especially in the field, the original appearance of the pre-existing rocks has been well preserved. Small lenses of chloritite frequently occur in the chlorite-albite rocks. They are original basic resisters. These rocks appear to be later than the late-Hercynian cross-cutting pegmatites. The age of the chlorite-albite rocks could not yet be determined. Possibly they are associated with the late-Hercynian period of faulting or with the Alpine orogeny. The influence of chloritization and albitization is also clear in gneisses and quartz-diorites near important fault zones.

The structural relations of the Trois Seigneurs massif with respect to the surrounding mesozoic rocks and the axial zone of the Pyrenees are discussed in the last chapter.

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