GEOLOGICAL MAP OF THE PALEOZOIC OF THE CENTRAL PYRENEES

SHEET 3, ARIÈGE, France
1 : 50.000

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Explanatory text

by

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(with one coloured geological map 1 : 50.000 Plate 1, and three sections, Plate 2)

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INTRODUCTION

Mapping of the Paleozoic of the Central Pyrenees by students in geology of Leiden University under the directorship of Prof. Dr L. U. DE SITTER started in 1948 with the Arize massif. Since then the survey has shifted first eastwards, 1949 St. Barthélemy massif; then westwards, 1950 Salat valley; 1951 Riberot valley (sheet 2); 1952, Garonne valley (sheet 1), and then southwards, 1953 and 1954 Valle de Arán, then south again to the Pallaresa and the Sègre (1955—1957).

The survey has been restricted almost exclusively to the Paleozoic because the Mesozoic had been mapped by CASTERAS (1933) in the north and by MISCH (1934), in the south, therefore only the Paleozoic rocks in their non-metamorphic and metamorphic state have been differentiated on the map, whereas the Mesozoic rock contours except part of the Triassic, have been taken over in a simplified form from the 1: 80.000 sheet Foix of the Carte géologique de France. Many internal reports and maps have accumulated in the files of the Geological Institute in Leiden of which only a few have been published. Often preliminary surveys have been succeeded by further detailed fieldwork by graduate students, other regions have been worked over again by ourselves so that now a start can be made with a final comprehensive series of maps on a scale 1: 50.000 of which Sheet 3, Ariège, France, containing mainly the satellite massifs of Arize, Trois Seigneurs and St. Barthélemy (see fig. 1) is the first to be published.

More space has been allowed for the metamorphic rock series than for the stratigraphic sequence, because the latter has been treated extensively before by many authors (LACVIVIER 1886, ROUSSEL 1904, CAREZ 1903—1909, DESTOMBES 1950, CASTERAS 1933, KEIZER 1954, ALLAART 1954) and the former have only recently begun to be studied from a modern point of view (RAGUIN 1938, GUITARD 1955, ZWART 1954, 1956, THIÉBAUT 1956, ALLAART 1958).

Of the present text the structural and stratigraphical part has been written by DE SITTER, the crystalline and metamorphic rocks are described by ZWART, but both of us feel responsible for the whole text and map.

The topographical base of the map is a reduction of the 1: 20.000 sheets which were either available in their definite or in their preliminary form. The production of the map is the result of the collaboration of our draughtswoman Miss C. ROEST and the printer MOUTON & Co., to whom we want to extend our sincere gratitude for their effort.

All chemical analyses have been made in our chemical laboratory by Mrs. Dr C. M. DE SITTER—KOOMANS to whom we are very gratefull for this important contribution.

Numerous students at different stages of their studies have contributed heavily to the map, they remain often anonymous, but their efforts are not forgotten neither by them we hope, nor by us. The principal authors are mentioned on the small index map on sheet 3.

CHAPTER 1

MORPHOLOGY

The physiographic expression of the principal structural units is almost perfect (see also figs. 1 and 2). The axial zone and the three independent satellite massifs consisting of Paleozoic rocks with a mantle of lower Mesozoic rocks, the Arize-, Trois Seigneurs-, and St. Barthélemy massifs (see structural map fig. 1) form the principal mountainous units of our map sheet. It is true that the Ariège river cuts through the more or less continuous ridge of the Arize-St. Barthélemy massifs and separates them along a line of no structural significance, but nevertheless the St. Barthélemy massif is structurally also an individual unit, separated from the Arize massif by some faults running east of the Ariège valley downstreams of Tarascon. The valley of the Upper Ariège, the Vicdessos and the Saleix valleys run along the North Pyrenean faultzone, the structural boundary of axial zone, and the Saurat valley runs along the fault separating the Arize and Trois Seigneurs massifs.

These river systems have a pre-glacial origin and have originated after the morphogenetic upheaval of the Pyrenean Mountain chain, which occurred at the end of the Miocene after a long post-folding erosion period.

The tectogenesis of the part of the Pyrenees represented by our map consists primarily of the Hercynian folding, followed later by a Laramide phase before the Cenomanian, and a Pyrenean phase in the Eocene. The post-folding denudation took place after the Pyrenean phase and lasted until the emergence of the mountain chain and finally resulted in a peneplain. During this period the marginal trough was being filled with Eocene and younger Tertiary sediments and this marginal region was again subjected to some paratectonic folding in the Miocene.

The dating of the morphogenetic upheaval rests on palynological examination of a small deposit in the central part of the axial zone (DE SITTER 1954) of which the detailed description has been given by Miss JELGERSMA at a congress in Barcelona, but which has not yet been published [1]). This deposit of Upper Miocene age occurs and has been preserved in a roughly 200 metres deep valley filled with conglomerates, sands, clays and lignite, cut into the well known high platform level at roughly 2000 metres altitude, representing the main original peneplain. Therefore the morphogenetic emergence of the central chain seems to coïncide roughly with the folding of the marginal trough. The peneplain, formed in the time between the Pyrenean folding and the Upper Miocene upheaval, is very well preserved as the Aston plat-

[1]) In the meantime published:
S. JELGERSMA.
Investigaciones palinologicas de lignitos terciarios procedentes de Cerdaña y del Valle de Arán (Pirineos españoles) Cursillos y conferencias del Instituto "Lucas Mallada", Fascículo IV, pp. 159—162, 1957.

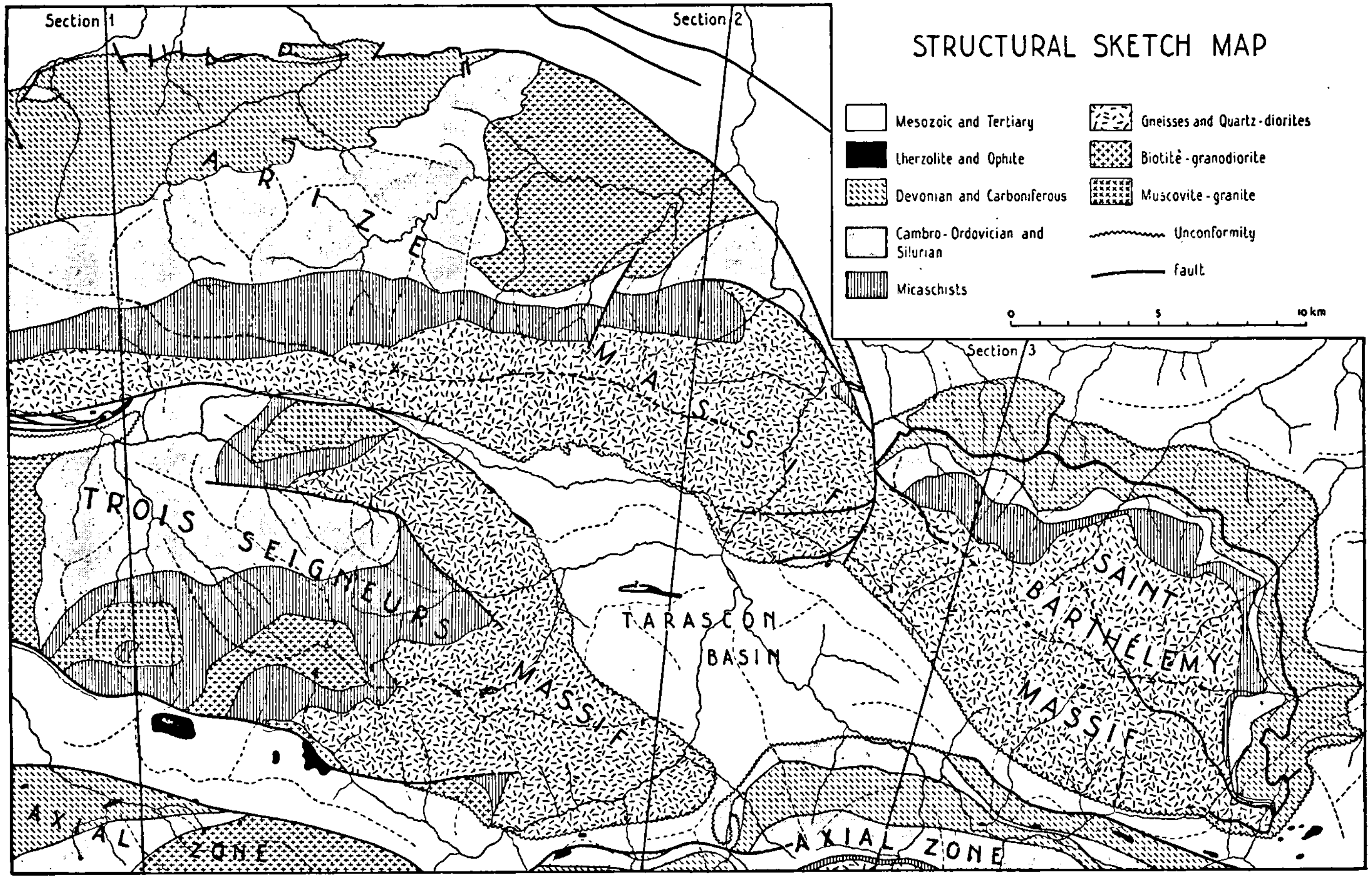

Fig. 1. sketch map of sheet 3, Ariège.

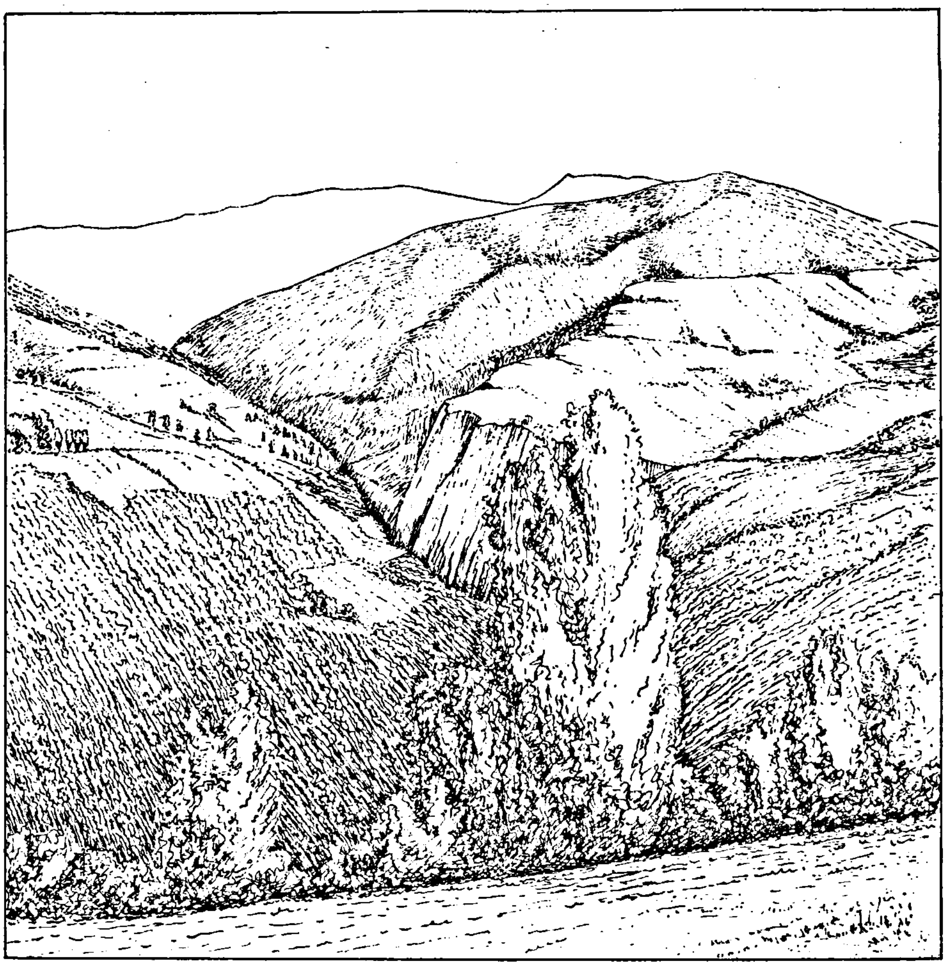

Fig. 2. One of preserved aplanation surfaces in the Arize massif near Esplas showing the contrast between the steep post-morphogenetic upheaval topography and the gentle older shapes.

form south of the Ariège river and continues unbroken over the Ariège valley and forms the high level of gentle hills preserved in the Barthélemy massif at 1800 metres altitude. It descends towards the north and in the Arize massif it is found round the 1600—1700 metre level (fig. 2).

Goron (1942) recognizes may other levels at a lower altitude, representing pauses in the upheaval process. As his dating of these surfaces can no longer be upheld since the discovery of the Upper Miocene deposit of the Valle de Arán, their mapping certainly needs a revision.

A peculiar feature in the morphology of the region is the contrasting behaviour of the Foix granitic stock on one hand and the Auzat and Trois Seigneurs batholiths on the other. The Auzat and Trois Seigneurs plutons stick out by virtue of their hard granitic rock as domes of greater altitude than their surroundings, whereas the Foix granite forms a distinctive depression due to its desintegration; in roadcuts the rock appears more as loose arcosic granite wash, than as a hard rock. This difference in weathering can reasonably be attributed to the fact that the present surface outcrop of the Foix granite is very near the pre-Triassic surface, its deeply weathered condition being due to a pre-Triassic weathering.

The High Platform and the riversystem have been remodeled by the glaciers. The steep valley walls often still show rounded and striated surfaces.

The upper parts of valleys show many rocksteps and small glacial lakes generally mark the bottom of the glacial cirques. The latter, with their steep slopes all around are often remarkably shallow, particularly so in the granitic regions.

CHAPTER 2

STRATIGRAPHY

Quaternary and recent deposits

As our survey was but little concerned with the glacial and later deposits, we will only indicate some of the major features and refer the reader to the existing literature for further detail, in the first place to GORON (1942).

The present river system, inherited from late Tertiary time developed after the morphogenetic upheaval of the Pyrenean chain. The Quaternary glaciations have remodeled the topography only slightly and principally by the moraine deposits in the bottom of the valleys and the glacial cirques above the High-Platform level (see fig. 3).

The Barthélemy and the Trois Seigneurs massifs have had their own glaciation independent of the main glaciation area of the axial zone. The cirques facing north are much better developed than the south facing ones. On our map they are mainly developed in the centre of Barthélemy massif round the Mt. Fourcat, Pic du Han and Pic du St. Barthélemy and in the Trois Seigneurs massif round the Pic des Trois Seigneurs.

The glaciers of the Touyre and Lasset valleys, descending from the Barthélemy massif, found their end respectively in the terminal moraines of Martinat, just upstreams of Montferrier and that of Montsegur about 1 km upstreams from the village of this name. Both terminal moraines possess a terrace extension downstreams.

In the Arize massif only very small cirque glaciers on the north and south facing flank of the central ridge had been developed.

The principal glacial deposits of our map are found however, in the Ariège valley, which derived its ice from the vast surface of the high level platform of the axial zone descending the tributaries of this main valley.

The distribution of foreign rock elements along the slopes of the Ariège valley and its tributaries prove without doubt that the thickness of the glacier was considerable, some 200—300 metres at least. The position of the still preserved terminal moraines in this valley just downstreams of Tarascon is not in agreement with this thickness, and therefore it seems probable that these terminal moraines only represent the fronts of the latest glaciation whereas those belonging to preceding older glaciations have not been preserved. On the same grounds and on other field considerations further downstream then our map reaches, GORON came to the same conclusion.

The existing terminal moraines which GORON distinguishes in the Ariège valley reflect three stages of retreat and each of them is connected with its own terrace downstreams. They are in upstream direction the moraines of Garrabet, Bonpas and la Bernière. The three terraces extending downstreams from these moraines constitute together the Middle Terraces. Some 35 metres higher we encounter the Upper Terrace just downstreams of Foix on the right bank of the Ariège which cannot be connected with a particular terminal

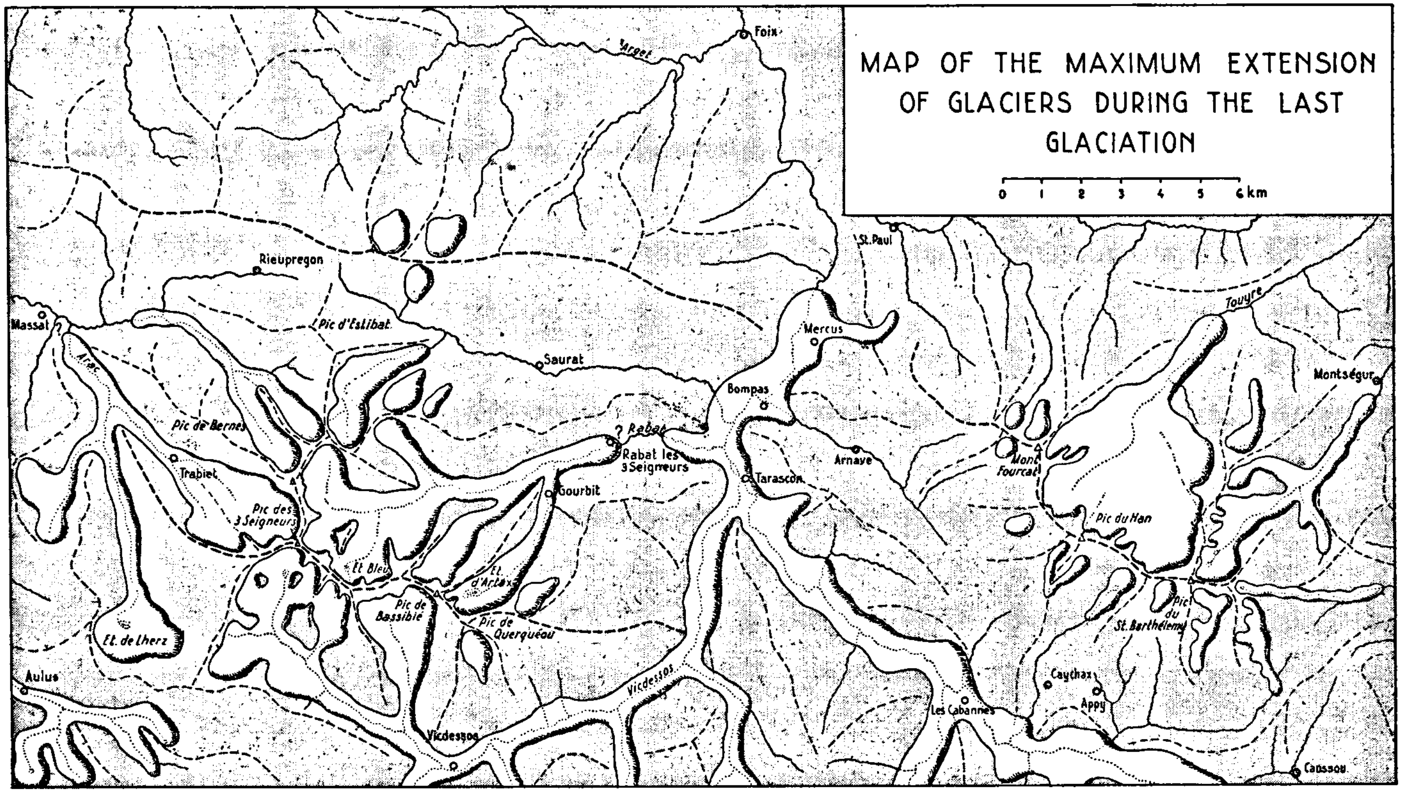

Fig. 3. Probable distribution of glaciers in the last glaciation of the Pyrenees.

moraine, and probably was connected with an older and more important glaciation as mentioned before. The Lower Terrace is due to the meandering of the Ariège river and reaches only a few metres above the present riverbed.

The filling up of the Ariège valley with a 300 metres or more thick ice stream prevented the functioning of the natural water outlet from the south facing flank of the Barthélemy massif. Instead of reaching the Ariège valley directly as they do now, these creeks were deviated towards the west and reached the Ariège valley by way of Cazenave and Arnave to Bonpas. During this ice age this parallel valley became clogged with fluvioglacial deposits which still form its present flat bottom. Similar filling up of tributary valleys happened along the Sentenac and Saurat valleys.

Mesozoic and Cenozoic

As our own mapping of the Mesozoic has been restricted almost exclusively to the formations on the boundary of the Paleozoic, we will treat them here only perfunctorily, and refer the reader mainly to CASTERAS (1933) for more detail. The main characteristics are the continental facies of the Triassic, the relatively thin development of the Jurassic, the thick series of the Lower Cretaceous interrupted by an unconformity at the base of the Cenomanian. The Upper Cretaceous-Eocene is poorly represented on our map and the post-Eocene sediments are almost lacking except the glacial deposits, the latter having been mapped only in so far as they blanket the older rocks.

Upper Cretaceous-Eocene

The Upper Cretaceous-Eocene sequence starts with the Cenomanian, which on our map is represented mainly on the northern margin of the Barthélemy massif. It is a coarse littoral facies often containing large blocks of Paleozoic rocks evidently tumbled down from coastal cliffs. It rests unconformably on the Lower-Cretaceous rocks in the Tarascon Mesozoic basin. Next to these coarse detrital rocks it shows also coral limestones of limited extend, as in the Tarascon basin, micaceous sandstones and marls. The coralline limestones occur often at the base. The limit with the Turonian is often uncertain by lack of fossils; in the Tarascon basin it is supposed that the top part of this succession consisting of an alternation of blue marls and micaceous sandstones belongs already to the Senonian. On the northern margin of the Barthélemy massif the Cenomanian has a very variable composition with lenticular limestones within marls and schists, conglomerates and breccias. The latter contain enormous blocks of Devonian limestone. Clearly it represents a coastal facies. The Turonian-Senonian consists of sandstones with occasional limestones. A conspicuous lithographic limestone of the Danian forms the top of the Cretaceous all along the northern border of the Pyrenees from the Garonne to the East. It is followed by claystones, sandstones and conglomerates of the Paleocene and then by alveoline limestones of the Lower Eocene.

Lower Cretaceous intrusives

Basic igneous rocks occur in the Pyrenees almost exclusively along the north Pyrenean fault zone. They are intrusive in the pre-Cenomanian Mesozoic rocks or in the Paleozoic sediments. They do not penetrate the hercynian crystalline rocks. Fundamentally they can be divided into two different rock types, viz. gabbros or diorites, called ophites, and peridotites, called lherzolites.

Similar ophites occur as sills or flows in the Keuper, for example in the western part of the Arize massif, just outside the map area. According to us they are different in age and geologic setting (ZWART 1954).

Since our French colleagues (RAVIER, 1958, CASTERAS, 1958) insist on a Triassic age of all ophites, in contrast with the Lower Cretaceous age of the lherzolites, we will discuss our conception somewhat in detail. Dating of igneous rocks depends very much upon the nature of emplacement, that is a lava flow or an intrusive body. The ophite of Castelnau-Lacourt in the Arize massif, lies in the Keuper and most probably represents a lava flow of Triassic age. When, however, a rock is emplaced as a sill or stock, it must be younger than the enclosing sediments. A terminus ante quem can only be found when pebbles of such rock occur in a younger conglomerate.

When all Pyrenean ophites should occur as flows and only in the Keuper, then their Triassic age could be considered well established. This is, however, not the case; on the contrary most of the ophites have not the appearance of flows but of intrusive bodies and, although both authors state that the ophite on the sheets of Foix and Bagnères de Luchon is always associated with the Keuper, a short look at both maps will suffice to convince us that this is wrong. Examples are on sheet Foix: the ophites at Lordat and Vernaux, occurring in Paleozoic rocks, at Lercoul in Jurassic, near Couflens in Paleozoic, at Arnave in Mesozoic, near Sentenac in Jurassic rocks and near Massat in Muschelkalk, and on sheet Bagnères de Luchon: near Castillon in Aptian, near Aucazein in Albian and Aptian, at Portet in Aptian (several ones), near Couledoux and Col de Mente in Aptian, south of Arguenos in Aptian and near Boutx in Jurassic and Aptian rocks. All these occurrences were not mapped by us, but by French geologists and we do not doubt that their maps are correct on this point. Thus the ophites are in contact with: Paleozoic, Triassic, Jurassic and Lower Cretaceous rocks and following the outlined principles on dating igneous rocks, they should be of Lower Cretaceous age or younger. Since they have not been found in Upper Cretaceous or younger rocks, there are good reasons to believe that these ophites were emplaced as intrusive bodies in post-Albian but pre-Cenomanian time. That these ophites are related to the lherzolites, is evidenced by their similar geologic setting along the north Pyrenean fault zone and by their mineralogical and chemical relationship (ZWART, 1954b). The outcrops of these two rock types are closely related especially on the line Castillon—Augirein—Portet—Moncaup on sheet Bagnères de Luchon.

Whether any Triassic rocks are present or not near ophite outcrops, is not essential in their dating, if it cannot be proved, that the ophite occurs as a flow. It is therefore doubtful, but not impossible, that the ophites near Massat, W of Quié and near the col de Carloung, are of Triassic age, but their geological setting close to the north Pyrenean fault rather suggests connection with Cretaceous ophites.

Finally we want to remark that we do not defend a new idea, but only a theory which French geologists have established long ago and which to our opinion, is more in accordance with the facts, than accepting an uniform Keuper age for all ophites.

Ophites. — The Pyrenean ophites are dark green or black rocks, which occur in outcrops restricted to a size of at most 1 km in length and a few hundred m in width. They are in contact with Ordovician, Silurian, Devonian or Mesozoic rocks. Due to bad exposures, contact relations are only seldom visible. In contrast with the lherzolites, the ophites occur close to all the branches of the north Pyrenean fault and not only immediately north of the axial zone.

The ophites are medium-grained rocks in which often light coloured feldspars and black or dark green pyroxenes or amphiboles are visible.

Microscopically the ophites contain plagioclase, ranging in basicity from andesine to labradorite, and pyroxene, often with diallage cleavage, in a clear ophitic intergrowth. The name ophite has not been derived from this texture but from the resemblance of these rocks to a snake skin. Ophitic texture has been defined after the Pyrenean ophites. According to the composition of the plagioclase these rocks can be classified as gabbros or diorites. Uralitization of the pyroxene it quite common and often no relics of this last mineral are present. The plagioclase is frequently albitized, but alteration into scapolite has also been described.

Lherzolite. — The lherzolites occur in a more restricted zone than the ophites, namely immediately north of the axial zone. West of the map area they follow however, a fault zone, which cuts Mesozoic rocks only. Another difference is that the lherzolites only occur in pre-Cenomanian Mesozoic limestones and not in Paleozoic sediments. This can however be purely accidental.

The largest outcrop is near the type locality of Etang de Lherz near Port d'Ercé, where a body of 1½ by 1 km is surrounded by lower Cretaceous limestones. Several outcrops occur east of Caussou, SE of the Saint-Barthélemy massif. Between these exposures and those of Etang de Lherz only a few small lherzolite bodies have been mapped.

The lherzolites are dark green or yellow green ultrabasic rocks, which consist mainly of magnesium-rich olivine, with minor bronzite, chrome-bearing diopside and a chrome-spinel (picotite). Partial serpentinization of the olivine is frequent, but complete alteration into serpentine is not common. The lherzolite of Bestiac, south of the Saint-Barthélemy massif is partly altered into chrysotile.

In the body of Etang de Lherz several other basic rocktypes have been described by Lacroix (1894). They often occur as dykes in the lherzolite and are called ariegites, lherzites, websterites or cortlandites. In general they are somewhat less basic than the pure lherzolites and, at least chemically, they are transitional to the ophites (Zwart 1954).

Alpine metamorphism, marmorization and scapolitization. — A very remarkable metamorphism accompanies the Mesozoic furrow in which the lherzolites and ophites occur. This metamorphism has been an object of interest during many years and a. o. Lacroix (1894, 1895) made a detailed petrological study of these rocks. Recently they have been restudied by Ravier (1958), but his final publication was not yet printed during the writing of this explanatory text. For this reason we will suffice with a short summary of the main features.

This peculiar metamorphism is restricted to the pre-Cenomanian Mesozoic rocks immediately north of the axial zone and does not follow the faults between the Arize and Trois Seigneurs massif, although some ophites are present in this area.

In Mesozoic rocks consisting of pure limestone, as for example the Urgo-Aptian, there is only recrystallization and marmorization of the limestone. More interesting rocks with various metamorphic minerals are formed at the expense of impure limestones, dolomites and shales, as for example the

Jurassic and Albian. Close to the lherzolite outcrops of Caussou and Etang de Lherz, a rather high-grade mineral association has been described, viz. bytownite, diopside, biotite, orthoclase, garnet, phlogopite and hornblende. The most characteristic minerals of the whole metamorphic zone are members of the scapolite group. These scapolites occur near the lherzolite contacts as well as elsewhere in the Mesozoic furrow. Associated with it are often somewhat lower grade minerals as clinochlore and albite. According to RAVIER (1954) the high grade assemblage is not restricted to lherzolite contacts, but occurs also further east, where no lherzolites have been found.

As to the cause of this metamorphism, which was locally of a high-grade character almost up to the surface, we suggest that the very important and deep reaching north Pyrenean fault, was an easy avenue for hot solutions, which were able to transform the Mesozoic sediments. It is equally important to note that only locally Paleozoic limestones participated in this scapolitization (a. o. near the Signal de Caussou). The age of the metamorphism is the same as that of the ophites and lherzolites, post-Albian and pre-Cenomanian, but it lasted somewhat longer than the formation of these intrusives, since the plagioclase of the ophites also can be scapolitized.

According to RAVIER the metamorphism predates the pre-Cenomanian folding and is contemporaneous with the sedimentation of the Albian.

We agree that this metamorphism is of a static type and not contemporaneous with the folding, but we consider it more likely that the metamorphism is later than the Laramide folding, but earlier than the Cenomanian.

Finally we want to state that the basic and ultra-basic intrusives and this metamorphism are in some way related. Probably both are dependent on the north Pyrenean fault cutting deeply into the earth's crust along which both intrusion and transport of solutions were facilitated.

Jurassic — Lower Cretaceous

The Lias starts with the Infra-Lias, little different from the Keuper, consisting of claystone and marls, cavernous dolomites and well bedded limestones, announcing the definite transgression of marine conditions over the continental Triassic. The Lower Lias contains gray dolomites and compact, sometimes oölitic, limestones, the Middle Lias consists of dark coloured marly limestones with ammonites, the Upper Lias contains black marls and sandy limestones. The whole is a typical shallow shelf facies with numerous small closed basins and bioherms.

In the Middle Jurassic we get a thick mostly dark coloured fetid dolomite of coarse grain, easily recognizable in the field. The Upper Jurassic is either missing or partly hidden in the top of the fetid dolomite, but it is certain that an erosion period somewhere between the Middle Jurassic and Lower Cretaceous carried away part of the limestones because it is here that we find the bauxite deposits of the Pyrenees.

The Lower Cretaceous starts with the thick and massif Urgonian limestone, typical of the whole Pyrenean territory. It has an Aptian age and is characterized by its clear colour and its rudist fauna (Toucasia). It is covered by an Orbitolina marl of Upper Aptian age containing occasionally big oysters. These Upper Aptian marls pass into the black marl and claystone facies of the Albian, which in its upper reaches carries phosphate layers and rare micro-breccias announcing the Laramid folding.

Triassic

The facies of the rocks covering unconformably the Paleozoic is typical for the european continental facies of the Triassic and shows grosso modo the classic sequence of red conglomerates and sandstones at the base followed by dolomite and limestone and red shales with occasional evaporites at the top, viz., Bunter-Muschelkalk-Keuper of the germanic facies. The complete absence of fossils gives us no possibility of any other subdivision. The conglomerates at the base have often been referred to as the Permo-Triassic, but evidence from the southern border of the Pyrenees rather indicates that the Permian does not form part of the basal conglomerate.

The Triassic is much more complete in the northern border of the Arize massif than in the Barthélemy region and is badly exposed in the region of Tarascon.

Keizer (1954) gives a series of detailed sections of the Triassic from the Arize massief (fig. 4) showing that, whereas the base is almost invariably formed by some 10—30 meters of conglomerates with rounded pebbles, it is followed by limestone breccia and limestone. The conglomerates contain next to quartz-pebbles quite a number of chert and limestone pebbles of Devonian and Carboniferous age showing that only a part of the detrital material is derived from afar and quite a lot from local sources. The limestone breccias on the other hand are purely local, they almost grade into the Triassic limestone.

A complete section always reads as a succession of conglomerates, red cross-bedded sandstones and shales at the base, shale, limestone breccias and dolomite-limestone, occasional cavernous dolomites in the middle and micaceous shales and marls with occasional gypsum beds at the top. The total thickness may reach as much as 300 metres, but is mostly thinner. Some basalts are intercalated at the top of the conglomerate-sandstone series in the Arize massif, and some andesites at the top of the dolomites. They are thin and wedge out rapidly. These volcanic rocks are typical lavas with cavities and glass matrix, very different from later basic intrusives.

In the triangular Mesozoic basin of Tarascon, of which Casteras (1933) made a special study, the Triassic is represented principally by the gypsum of Arnave and Arignac respectively in the right and left border of the Ariège river just below Tarascon. The gypsum is associated with cavernous dolomites and limestone and contains bipyramidal quartz prisms.

Paleozoic

Introduction

The stratigraphy of the Paleozoic rests for a large portion on the observed sequence of the rocks, their fossil content being poor. The lower boundary is lost in highly metamorphic rocks, the upper limit is formed by the very pronounced unconformity of the Triassic.

Age determinations are available by the graptolite fauna of the black Silurian shales, some occasional goniatites mostly in the Upper Devonian nodular limestones (griotte) and a rare goniatite fauna in the Carboniferous. Fortunately the black shales facies of the Silurian, the griotte of the Upper Devonian and that of the cherts of the Lower Carboniferous are conspicuous, otherwise a consistent mapping of the structures would have been impossible.

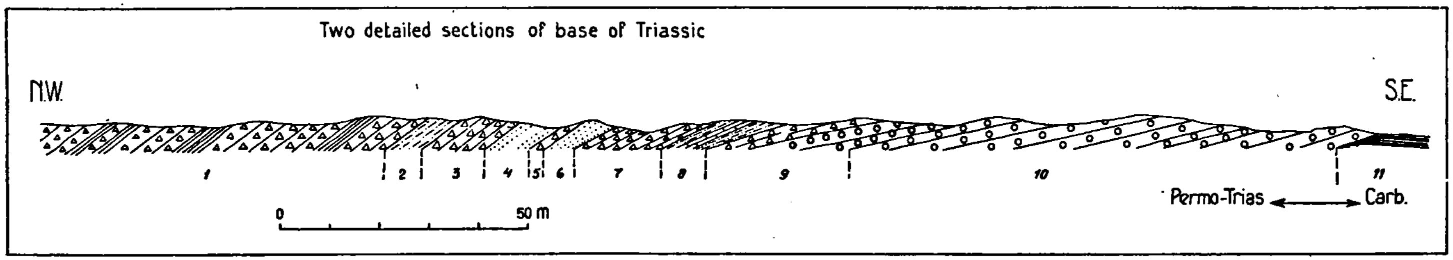

Fig. 4a. Section of the Triassic on the road Rimont-Cuilleré. 1. limestone breccia with chert fragments, alternating with red and gray shales; 2. gray clay; 3. chert breccia; 4. sandy limestone; 5. breccia; 6. red sandy limestone; 7. chert and quartz breccia; 8. limestone alternating with limy shales; 9. red breccia; 10. coarse conglomerate with limestone pebbles; 11. red conglomerate with sandstone, limestone and dolomite pebbles; 12. Visean slates. (After KEIZER 1954).

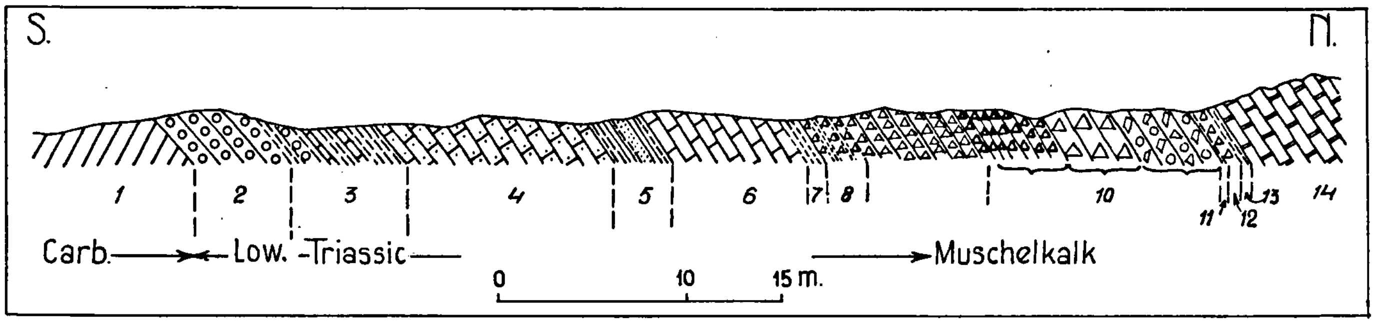

Fig. 4b. Section of Triassic north of Castle of Larbont. 1. Visean slates; 2. well stratified red conglomerates; 3. red shales alternating with limestones; 4. red sandy limestone; 5. shales and sandy limestones; 6. red limestone; 7. gray clay; 8. limestone breccia and red shales; 9—10. limestone breccia with chert fragments near the top; 11. shale; 12. limestone breccia; 13. clay; 14. dolomite. (After KEIZER 1954).

The principal folding took place somewhere in the Westphalian and was accompanied by strong metamorphism and followed by intrusive rocks, granite batholiths and a series of dykes.

Late carboniferous intrusives

Under this head various rocktypes are united, which together form intrusive granitic rocks and their dykes. These rocks are in general later than the Hercynian folding and can occur both in regional metamorphic and unmetamorphosed rocks. The largest bodies are formed by biotite-granodiorite and quartz-diorite. The lamprophyres and porphyrites have only been found as rather small dykes. The biotite-granodiorite and quartz-diorite stocks are surrounded by a contact metamorphic aureole.

1. *Biotite-granodiorite to quartz-diorite.* — Four rather large bodies and a few smaller ones of biotite-granodiorite to quartz-diorite occur in the map area. One lies in the Arize massif, two in the Trois Seigneurs massif and one in the Axial Zone. These are called the granite (or better granodiorite) of Foix, the granodiorite of the Pic des Trois Seigneurs, the granodiorite of Oust and the granodiorite of Bassiès-Auzat. The last one, by far the largest of these four plutons is only partially represented on the map. All four granodiorite batholiths are quite homogeneous and show sharp contacts with the enclosing rocks.

The granodiorite of Foix lies in a topographic depression, probably caused by the pre-Triassic deep weathering of the granodiorite. Most of the outcrops are deeply altered and it is difficult to procure a fresh specimen. This body lies almost entirely within Cambro-Ordovician phyllites; locally Silurian rocks are in contact with the granodiorite. A contact aureole of a few hundred metres width surrounds this body.

The granodiorite is a grey coloured rock in which quartz, feldspar and biotite can easily be spotted. The rock is completely unoriented, except for some weakly gneissose rocks near the contracts. Inclusions are rare. The rock is medium grained. Microscopically the following minerals have been observed: quartz, plagioclase (andesine), microcline and biotite as main constituents and apatite, zircon and ore as accessories. The andesine is present as idiomorphic or hypidiomorphic grains, often beautifully zoned with many oscillations. The core is more basic than the rim. Quartz occurs as an interstitial mass between the plagioclase and biotite crystals. Microcline is found in minor quantities and often strongly corrodes plagioclase. Biotite occurs as more or less idiomorphic plates.

According to de Sitter (1954) this granite has had a strong structural influence on the rocks on its northern side, resulting in a doming and pushing aside of the phyllites. This indicates that this granite has made its place by shouldering aside the surrounding rocks, hence its intrusive character. Also its situation in very low grade sediments can be explained by emplacement as a result of intrusion.

The contact rocks consist of spotted phyllites, the spots consisting of andalusite, often completely sericitized. Also biotite-hornfelses have been found.

In many respects the granodiorite of the Pic des Trois Seigneurs is similar to the granodiorite of Foix. The first lies, however, not in phyllites as the latter does, but in medium grade regionally metamorphosed mica-schists. Its outcrops are much better, due to its situation at high altitude.

The influence of this granite on its wall rock is of importance, since it could be proved that secondary structures have been formed in the adjacent mica-schists as a result of the intrusion (ALLAART, 1958). Also the metamorphic grade on both sides of the granodiorite is entirely the same, indicating that there is nothing missing in the sequence of metamorphic rock in the space now occupied by this granodiorite body. Very striking is that, although the granodiorite looks quite discordant on the map, in detail the contacts are always conformable. On the E side of the body, where the mica-schists dip to the west, the contact has the same dip, resulting in granodiorite overlying mica-schist. All these observations are adequate arguments for an intrusive emplacement of this stock.

Mineralogically this granodiorite is similar to the one of the Arize massif. Plagioclase, usually andesine, occurs as hypidiomorphic, strongly zoned crystals, quartz is interstitial and microcline in minor amounts often replaces plagioclase, sometimes associated with the formation of myrmekite. Accessories are zircon, apatite, orthite, ore and sometimes green hornblende.

The contact aureole in the mica-schists is restricted to a zone of at most hundred metres wide. The mica-schists are strongly recrystallized to sillimanite-biotite-muscovite rocks, in which especially sillimanite is present as large crystals. Further away from the contact the unoriented texture is gradually replaced by the schistose texture of the mica-schists. The occurrence of static recrystallization in the migmatites has wrongly been interpreted as contact metamorphism (NIEUWENHUYS 1956, THIÉBAUT 1956). This feature belongs to the regional metamorphism and occurs in all migmatite areas, irrespective of proximity of intrusive granites.

The granodiorite of Oust, of which only a small border is represented on the map, is in almost every respect similar to the granodiorite of the Pic des Trois Seigneurs. Its contact aureole is somewhat larger, especially in the Cambro-Ordovician phyllites, and actually exceeds the distribution shown on the map.

Two other small stocks occur in the Trois Seigneurs massif near Les Bordes and Suc, either originally belonging to the massif of the Pic des Trois Seigneurs, but sheared off by later faulting, or to the Auzat massif.

The granodiorite of Bassiès-Auzat shows in general the same features as the already described stocks, but this granodiorite is somewhat more leucocratic. On its northern side this granodiorite is in contact with Cambro-Ordovicien phyllites, but near the Port de Saleix it just touches Silurian sediments. This batholith has a somewhat discordant contact with its wall rock.

The mineralogical composition and the texture of this granodiorite are similar to those of the described stocks.

The contact aureole has a thickness of approximately 500 m. The phyllites are altered into spotted schists and biotite hornfelses. Lime-bearing rocks have been transformed into epidote-clinozoisite hornfelses. The limestones have been changed into white marbles, sometimes tremolite-bearing.

The following chemical analyses have been executed, (table I, p. 370). The most striking feature of the comparison of these nine analyses is their uniformity.

2. *Lamprophyre dykes.* — Lamprophyre dykes are rather scarce in the mapped area. A few have been encountered in the Trois Seigneurs massif and in the Arize massif. In the Trois Seigneurs massif the dykes occur in the granodiorite, whereas the dykes in the Arize massif have been found in the migmatites.

TABLE I

Biotite-granodiorite

Analysis no.	1	2	3	4	5	6	7	8	9
SiO_2	60.48	62.42	62.59	63.60	63.82	64.25	65.75	65.75	68.52
TiO_2	0.88	0.72	0.73	0.72	0.79	0.64	0.48	0.46	0.54
P_2O_5	0.32	0.20	0.19	0.24	0.24	0.18	0.03	0.14	0.06
Al_2O_3	16.22	16.84	17.20	16.20	16.59	16.30	16.81	16.68	14.92
Fe_2O_3	0.52	1.64	1.09	1.09	1.48	1.51	0.57	0.65	0.96
FeO	4.08	4.14	3.66	3.84	3.66	3.07	3.44	2.91	2.79
MnO	0.06	0.13	0.18	0.05	0.10	0.10	0.03	0.07	0.11
MgO	2.93	2.24	2.56	2.29	1.39	2.72	2.02	0.99	1.25
CaO	4.42	5.32	4.69	4.33	5.36	4.08	3.63	4.50	4.12
Na_2O	2.77	3.52	3.08	3.16	3.00	3.14	3.30	3.32	3.40
K_2O	3.24	1.96	2.70	3.42	2.16	3.30	2.96	3.30	3.12
CO_2	1.74	—	—	—	—	—	—	—	—
H_2O	2.54	0.91	1.06	1.22	1.60	0.97	1.18	0.76	0.73
	99.92	100.04	99.73	100.16	100.19	100.26	100.20	99.53	100.52

1) Granodiorite of Lacourt, western part Arize massif
2) Granodiorite of Les Bordes, Trois Seigneurs massif
3) Granodiorite south Etang d'Arbu, Trois Seigneurs massif
4) Granodiorite of Foix, Arize massif
5) Granodiorite of Suc-Orus, Trois Seigneurs massif
6) Granodiorite of Pic des Trois Seigneurs, Trois Seigneurs massif
7) Granodiorite 1½ km north Pic des Barres, Trois Seigneurs massif
8) Granodiorite of Bassiès-Auzat, contact facies
9) Granodiorite of Bassiès-Auzat.

One of the lamprophyres, occurring in the Trois Seigneurs massif is a microdiorite. It contains zoned plagioclase (cores of andesine with rims of albite or oligoclase), biotite, green hornblende and minor quartz.

West of the Pic de Barre a barkevikite bearing lamprophyre was found. Titaniferous augite occurs as phenocrysts in a groundmass of basic plagioclase and barkevikite.

3. *Porphyrite dykes.* — In the Carboniferous and Devonian sediments of the Arize and Saint-Barthélemy massifs many small outcrops of brownish weathered porphyritic rocks have been found. Due to lack of good exposures it could in general not be determined whether these intrusives occur as dykes or as sills. The two largest ones in the Arize massif are sills.

The fresh rock is generally blue-grey and shows white phenocrysts of feldspar in a dense matrix. Under the microscope most of these rocks are strongly altered. Often there is some introduction of calcium, expressed as calcite veinlets. The phenocrysts consist mainly of sodic plagioclase, but once a more basic plagioclase was observed. The plagioclase is always strongly sericitized. Quartz and chloritized biotite also occur as phenocrysts. The matrix consists of sericitized plagioclase, quartz, potash feldspar, biotite, sericite and chlorite. Depending on their mineralogical composition these rocks are quartz-diorite-porphyries, diorite-porphyries or granite-porphyries.

A particular rock has been found on the ridge between the creeks of Lasset and Basqui. This rock contains phenocrysts of albite and masses of chlorite probably as alteration products. Finely divided ore in the matrix proved to be hematite. This rock, which shows associations with spilites, is probably a metasomatically altered basic dyke.

The age of these rocks is most probably Carboniferous. They are intruded after the Hercynian folding, but do not occur in younger sediments. Although direct relationships with the granodiorites have not been observed, they probably are related to these rocks.

4. *Contact aureole.* — The contact metamorphism has been dealt with in the description of the biotite granodiorite.

Carboniferous

The Carboniferous of the northern border zone of the Pyrenees is essentially of marine origin and is characterized by a conspicuous horizon of 0—40 metres thickness of well bedded cherts at its base. It is followed in general by a thick well stratified sequence of shales and sandstones. Its thickness measured in the synclines does not seem to exceed 1000 metres, but the top is not exposed.

The cherts are a curious formation. They are interstratified with thin black shales containing phosphate nodules and they carry a marine fauna of goniatites (DELEPINE, 1929) and a few well preserved plant remains (Lepidostrobus, Lepidodendron). The cherts are often lacking and are sometimes replaced either by a fine grained breccia containing chert fragments or, further to the east outside our map, by a conglomerate with chert pebbles. Evidently this facies indicates occasional and local emergence in a shallow sea environment. Its age is Lower Visean and the absence of the Tournaisian between the Upper Devonian and the cherts points into the same direction of a period of interrupted deposition. On the other hand we find above the cherts occasionally the same griotte facies represented by a limestone band sometimes reposing directly on the cherts, whereas the top layers of the Upper Devonian often are silicified and thus form a transition towards the black cherts (fig. 5). The same circumstances have been found to the NE in the Montagne Noire. Nowhere in the Pyrenees or adjacent regions the base of the Upper Carboniferous rests on anything else but the Upper Devonian and everywhere the sequence is perfectly conformable.

The age determinations of the crucial horizons round the hiatus at the base of the Carboniferous are assembled from widely scattered outcrops and in consequence there is still some doubt about the validity of the supposed absence of the Tournaisian. Nevertheless the presence of conglomerates both in the Upper Devonian and in the Visean, and both of a monomict character leave no doubt that some epeirogenic movements occurred.

The shale-sandstone sequence of the Carboniferous has an Upper Visean age (DELEPINE, 1935) after the content of the fossil localities in the Arize massif near St. Girons, Mondette, containing goniatites (*G. granosus, G. falcutus*) and near Larbont containing brachiopods (*Productus giganteus* etc.).

Towards the western part of the Arize massif and in the Barthélemy massif the sand content decreases and the series becomes less well stratified. The sandstones, mostly in thin bands are often arcosic.

The Devonian

Below the black cherts of the Carboniferous and above the black slates of the Silurian we find a calcareous suite of rocks which by its occasional and very local fossil content belongs to the Devonian.

As a subdivision in Lower, Middle and Upper Devonian is generally not possible by paleontological evidence over large tracts of the central

Pyrenees we have adopted a system of lithologic subdivision which gives at least a cartographic expression of the structure. Occasionally lithologic correlation with fossil bearing sequence does allow a rough subdivision in Lower-, Middle- and Upper Devonian, in particular in the Arize massif, and because lateral facies changes seem to be small this subdivision could be carried forward to the Barthélemy massif, with the result that the lithological subdivision has a direct but rough stratigraphical sense on sheet 3 of our map.

The top of the Devonian series is characterized by the griotte (= patched

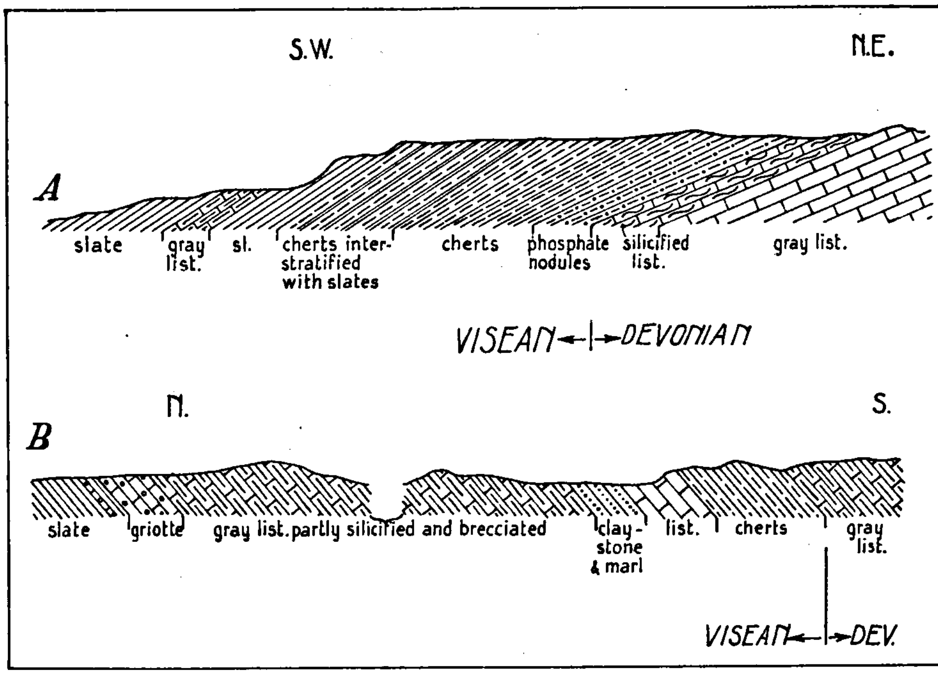

Fig. 5. The transitional facies of the boundary zone between Devonian and Carboniferous in the Arize massif (after KEIZER, 1954).

nodular limestone) facies, the lower part locally by claystone or slates of greenish to violet colour. The nodules are sometimes much corroded goniatites (*Cheiloceras*), but more often they are simply 2—15 cm. flattened nodules of very finegrained limestone in a shale matrix of a different colour. The nodules vary in colour from white to pink and red, the darker coloured matrix from green to violet. The proportion limestone nodules-shale matrix varies between a shale with rows of nodules to a massif patched limestones with hair thin wavy shale partings. The rock is particularly susceptible to cleavage and because nowhere in the Pyrenees the Paleozoic is unfolded, it remains doubtful how much of the particular aspect of the griotte is due to tectonization and how much to its original sedimentary structure.

Towards the top the red griotte limestone becomes white and gray and sometimes changes into a white to gray massive fine grained limestone, locally even silicified.

In the Arize massif the griotte limestone is underlain by green and violet calcareous slates, the boundary is transitional by a simple decrease upwards of the nodules. The same facies change occurs laterally, with the result that sometimes the slates are absent and sometimes the limestone.

The total thickness of the Upper Devonian reaches 150—200 metres in the Arize massif. Small beds of limestone conglomerates of 1 to 1,5 metres thickness have been reported by KEIZER (1954), fig. 6, and SCHMIDT (1931) from several localities in the Arize massif and by ALLAART (1954) from the isolated outcrop near Lordat in the faulted zone south of the Barthélemy massif. They do not seem to be bound to a definite horizon, but apparently are due to local emergences. They do not contain anything else but limestone pebbles, well rounded and having a diametre up to 10 or 15 cm.

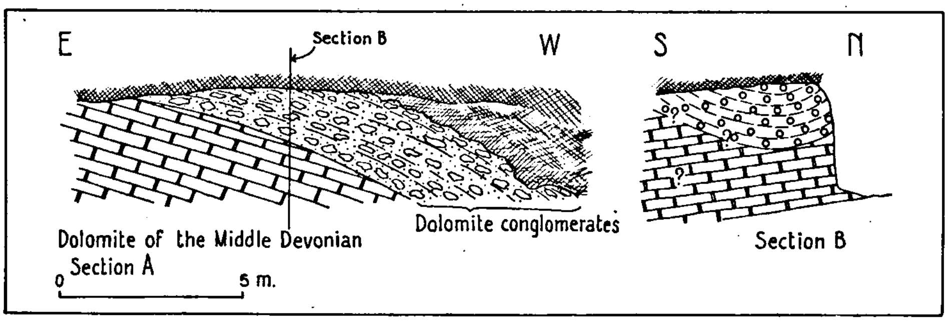

Fig. 6. Devonian monomict conglomerates on the northern border of the Arize massif near Castelnau Durban (after KEIZER).

From the Barthélemy massif ZWART (1954) reports from several localities brecciated limestone intercalated with the white limestone.

Goniatites in cross section are very often recognizable in the griottes but they are very rarely well enough preserved to allow determination, and a subdivision of the Upper Devonian on paleontological evidence is impossible. *Clymenia, Oxyclymenia, Cheiloceras* and coral remains have been reported from various localities.

From the Spanish side of the Pyrenees we know that the griotte facies represents the Frasnian and Famennian (SCHMIDT, 1931, ROUSSEL, 1903—1904).

The griotte limestone is believed to be a shallow water facies where wave action has disturbed the banding of clay and calcareous sediments. The corrosion of the fossils, the occurrence of breccias and even conglomerates and occasional coral remains, the rather rapid lateral facies changes all point in the same direction.

Dolomitization is rather common and invades the rock very irregularly. This secondary dolomitization could perhaps be ascribed to the supposed emergence of the whole Pyrenean basin during the Lower Carboniferous, or perhaps to magnesium rising from below where the process of regional metamorphism expelled this element.

In the eastern part of the Barthélemy we find a marmorization of all the Devonian limestones which penetrates also into the Upper Devonian and makes them considerably less distinctive.

In this part of the Pyrenees a massive limestone occurs below the griotte or the multicoloured slates facies of the Upper Devonian, probably representing the Middle Devonian. In the western part of the Arize massif it consists of an upper 100—150 metres of dolomite and a lower 30—120 metres of bluish coarse grained and well bedded limestone, in which large calcite crystals are evenly distributed, probably representing echinoderm fragments. In the Barthélemy massif the limestone has been marmorized to a great extent and southwards in this massif the distinction between the calcareous slates of the Lower Devonian and Middle Devonian massive limestone disappears by the development of a monotonous repetition of limestone and limy slates. This latter facies is typical of a large part of the axial zone of the Pyrenees (fig. 7).

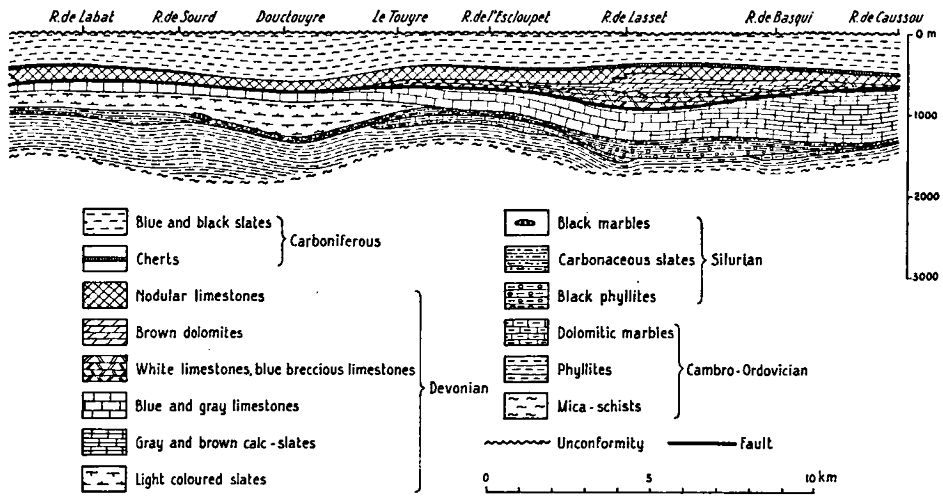

Fig. 7. Development of the Paleozoic in the St. Barthélemy massif (after ZWART, 1954).

The fossil content of these limestones in our region has not provided us with a good fauna, it contains numerous fragments of bryozoaires and echinoderms, and some brachiopods. Crinoïd stems are often plentiful.

The total thickness of massive limestone-dolomite facies is 150—250 metres.

The base of the Devonian in the Arize and Barthélemy massifs is sometimes formed by calcareous slates which have delivered in the Artillac valley of the Arize massif a sequence of two faunas indicating the Gedinnian and the Coblentzian (ROUSSEL, 1903—04). In general, however, this slate formation is lacking between the black slates of the Silurian and the limestones and are presumably replaced by limestones. One outcrop on the northern border of the Arize massif of red ferruginous and calcareous sandstone below the slates delivered a fauna of brachiopods (*Atrypa*), trilobites (*Lichas haueri* Barrande) and crinoids (KEIZER, 1954), fig. 8.

In the northern part of the Barthélemy massif the slate facies at the base of the Devonian is well developed, although devoid of fossils, but further to the east and south the difference between the massif limestone facies and slate facies disappears and makes place for a continuous alternation of slates and limestones. The same is true for the region south of the Trois Seigneurs and Barthélemy massifs. In the axial zone further south, outside the region of our map, in the Valle de Aran for instance, the role of the limestones and slates is reversed, there the limestones at the base are followed by a slate formation.

Silurian

Between the sericite schists of the Ordovician and the limestones, calcareous slates or slates of the Devonian we find in every undisturbed section a series of black carbonaceous slates which by their graptolite fauna has been proved to belong to the Silurian. As these slates are particularly incompetent they have often been squeezed out partially or completely or, on the contrary have been accumulated into thick slickensided masses.

No doubt this tectonical aspect accounts for the fact that nowhere in the northern Pyrenees a good subdivision of one section can be made although all the different Silurian horizons have been reported, but each from a different locality.

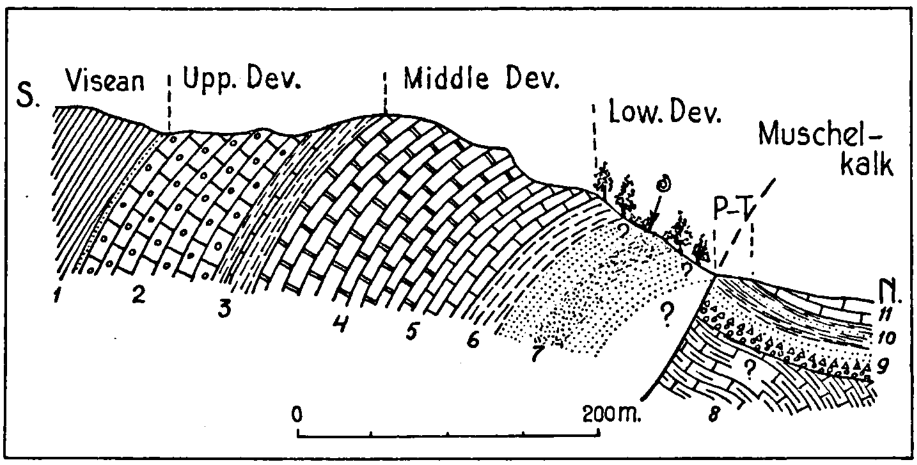

Fig. 8. The Devonian on the northern boundary of the Arize massif with fossil locality of the Lower Devonian (after KEIZER, 1954).

The same tectonization can account for the widely divergent thicknesses (from 0—3000 m) which have been reported by various authors. The maximum figure is certainly a gross exaggeration, and we would think that 200 metres will be a good approximation.

Moreover both downwards and upwards the black slates grade into the preceding or succeeding formations. The black slates occasionally contain black limestone lenses or bands with orthoceratidae and brachiopodes (*Cardiola*). They are invariably very ferruginous when they are black and we presume that their black colour is more due to a finely disseminated iron sulphide than to graphite. Their iron content is shown clearly by the rusty colour of the water of its frequent sources.

Occasionally they lose their typical black aspect and then the cartographer is often at a loss to distinguish the Silurian on his map.

Cambro-Ordovician

Everywhere in the Pyrenees we find in the lower part of the Paleozoic below the Silurian a sedimentary unit formed by a thick series of slates, phyllites, sandstones, quartzites, microconglomerates, conglomerates and occasional calcareous sediments, which have not delivered a recognizable fauna except very rarely and then only at the top. We call this thick sequence of mostly neritic facies the Cambro-Ordovician because it has been suggested (CAVET, 1951) that the Cambrium is included in this formation, although we do not know whether the Eocambrium or some of the Pre-Cambrium is not included also.

From the southern Pyrenees (DALLONI, 1930) and recently also from the northern part of the axial zone (AUTRAN and GUITARD, 1955) and the Trois Seigneurs massif (THIÉBAUT, 1956) we know, that the upper calcareous horizon of the Cambro-Ordovician has a Caradoc age.

In the northern zone of the Pyrenees and particularly on our sheet 3 most of the Cambro-Ordovician has been subjected to a strong, regional metamorphism and therefore its metamorphic rock sequence will be described further on and we will deal here only with those portions of this formation in which the original sedimentary lithology is still their distinguishing characteristic.

Sericite-phyllites. — In the northern margin of the axial zone we find from top to bottom a sequence of slates and sericite-phyllites with a gradual transition from one kind of rock to the other. The top part contains occasionally a limestone layer with occasional crinoid stem debris and above it some calcareous slates. Below the limestone horizon the sericite schists contain locally microconglomerates and pebble beds.

In the Arize massif the top part is more sandy than further down and does not contain any calcareous layers, except perhaps the mineralized dolomite lens of Mont Coustant.

In the Trois Seigneurs massif the weakly metamorphic Cambro-Ordovician consists, as elsewhere, principally of phyllites with occasional more sandy bands. In the metamorphic sequence we find metamorphic limestones which often suggest a single stratigraphic horizon as for instance round the syncline north of the Pic des Trois Seigneurs, one might suggest that they represent the "zone de Canaveilles" of the eastern Pyrenees (CAVET, 1951). Similar belts of metamorphic marbles run along the southern margin of the Barthélemy massif. One of them crosses the Ariège river near Mercus and then enters the Arize massif where it can be followed beyond Saurat.

Their stratigraphic value will always remain unknown as we have no means to judge the original structure inside these metamorphic rock sequences.

The original pelites have been metamorphosed to phyllites during the Hercynian folding, mainly by dynamic metamorphism. Except S. of Aulus, where the phyllites are in contact with the granodiorite of Bassiès-Auzat, the phyllites grade downward into mesozonal mica-schists. The thickness of this phyllite series is quite variable; it is zero in the eastern part of the Saint-Barthélemy massif near Trimouns, but reaches several thousands of metres in the central part of the Arize massif. Since both massifs formed originally one continuous unit, the thickness increases gradually from E to W. This is due to the variable position of the lower boundary of the phyllites, viz. the biotite isograd, or in other words, the metamorphic front has risen higher into the sedimentary series going from W to E.

The folding of the phyllites is a cleavage folding in which sometimes the bedding makes an angle with the cleavage, as was observed for example near the Pic de Journalade in the Trois Seigneurs massif. More often, however, the folding is isoclinal and bedding and cleavage are parallel, as is also frequently the case in the mica-schists. Although on the map cleavage is supposed to be present in the phyllites and schistosity in the mica-schists, there is no fundamental difference between these two features and the cleavage in the phyllites and the schistosity in the mica-schists grade into one another. This difference has been drawn, because on other sheets, which will appear shortly, there is a distinct cleavage folding in the Cambro-Ordovician and Devonian, without any higher grade regional metamorphism being involved.

Larger folds can only rarely be observed in the phyllites; microfolding of the cleavage plane is, however, almost everywhere present. In most cases this microfolding is visible as a crumpling and it is a b-lineation because larger folds are nearly always parallel to these microfolds. Occasionally a lineation is perpendicular to the general strike and consequently is an a-lineation.

The attitude of the cleavage is variable, but mostly a rather steep dip is present, as for example in the Arize massif and in the Trois Seigneurs massif. Locally in the Saint-Barthélemy massif, for example in the Labat creek, the phyllites are flat lying over a considerable distance.

In general the phyllites have grey or brown colours and locally they are intercalated with black graphitic schists, dark coloured quartzites and exceptionally coarse grained quartzites to microconglomerates. The cleavage planes are lustrous, due to fine-grained sericite: "schistes satinés" or "schistes lustrés". Sometimes a distinct banding is present, due to the occurrence of layers and lenses of exudation quartz, which are generally not thicker than a few mm. In general the phyllites are rather homogeneous and when they occur in thick beds, a monotonous rock series prevails.

Microscopically the main constituents are quartz, sericite and chlorite (penninite); less abundant are potash feldspar and albite. Graphite, tourmaline, zircon, apatite, rutile, ilmenite and pyrite occur as accessories.

Towards the biotite isograd the phyllites become distinctly coarser grained and often richer in sericite. The mineralogical composition is identical with that of the normal phyllites.

TABLE II

Sericite-phyllites

Analysis no.	Aston massif		Arize massif		Trois Seigneurs massif	
	10	11	12	13	14	15
SiO_2	56.95	57.26	58.72	60.25	63.10	65.00
TiO_2	1.31	1.32	1.60	1.40	1.16	1.17
P_2O_5	0.31	0.23	0.29	0.29	0.29	0.29
Al_2O_3	20.64	20.79	20.09	19.21	17.29	16.21
Fe_2O_3	3.97	4.03	5.34	5.58	2.75	2.86
FeO	6.55	4.24	4.30	3.57	4.75	4.13
MnO	0.02	tr.	tr.	tr.	0.02	0.02
Mgo	2.21	1.46	0.72	1.17	1.44	0.86
CaO	1.62	1.54	1.58	1.21	0.98	1.29
Na_2O	1.65	1.60	1.48	1.50	1.70	2.45
K_2O	3.45	3.65	3.28	3.15	3.52	2.68
H_2O	1.40	3.93	2.94	2.91	3.34	2.87
	100.08	100.05	100.34	100.24	100.34	99.83

In order to get an impression of the chemical composition of these phyllites 6 analyses have been made by Dr. C. M. DE SITTER—KOOMANS, Table II. Each of these 6 analyses represent an average of 10 field samples, two originate from the Arize massif (along the road Serres-Burret), two from the Trois Seigneurs massif (along the road Le Port-Massat) and two from the Aston massif south of the map area along the road Auzat-Marc.

Calcite and dolomite marbles. — Crystalline white marbles occur at two places in the map area, in the E part of the Saint-Barthélemy massif and S of Aulus in the axial zone. Near Trimouns in the Saint-Barthélemy massif dolomitic marbles occur immediately below the Silurian black shales. North of Trimouns these marbles wedge out, but near the Porteille quarry the horizon reappears, to disappear again in the Touyre valley; it is not found further west, neither in the Trois Seigneurs, nor in the Arize massif except perhaps the mineralized dolomite lens of Mont Coustant. The greatest thickness of the marble is approximately 100 m. The marbles contain locally some graphite, which is concentrated in layers due to metamorphic action. The grain size is rather large, up to a few mm. Near Trimouns and Porteille important talc deposits are worked in quarries, which occur at the base of the dolomitic marble. We will return to this subject in the chapter on economic deposits. One analysis of a dolomitic marble originating from the Trimouns quarry has been executed, Table III.

TABLE III

Analysis no.	16
CaO	29.43
MgO	19.40
CO_2	43.43
Fe_2O_3	0.89
C	0.93
H_2O	1.02
Silicate	4.27
	99.67

South of Aulus several calcitic and dolomitic marbles up to a thickness of several hundred metres are intercalated in the phyllites in the upper part of the Ordovician. Here these marbles are also coarse grained and white; locally they are dolomitic.

Isochemical metamorphic facies of the Cambro-Ordovician

The rocks which are the isochemical metamorphic equivalents of the Cambro-Ordovician sediments, consist mainly of mica-schists in which one or two different metamorphic zones can be distinguished. Locally lime-silicate rocks occur, derived from marls or limestones. These mica-schists and lime-silicates form the transition between the non-metamorphic Upper Paleozoic and the gneisses, granites and migmatites which in the map area form the deepest exposed rocks.

Mica-schists. — Going downward the phyllites change gradually into biotite-muscovite schists. The boundary between these two rocktypes is the biotite isograd, which also represents the boundary between epi- and mesozone.

TABLE IV

Mica-schists

Analysis no.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
SiO_2	48.12	54.90	55.70	56.61	57.04	57.30	58.05	58.56	58.70	59.02	59.98	62.48	63.48	63.70	65.08	69.18	73.12
TiO_2	1.63	0.82	1.09	0.96	1.11	1.09	1.52	0.91	1.21	0.95	1.07	1.20	0.94	1.08	1.44	1.06	0.98
P_2O_5	0.30	0.22	0.28	0.30	0.22	0.25	0.16	0.44	0.29	0.25	0.26	0.31	0.32	0.22	0.26	0.07	0.23
Al_2O_3	29.00	20.70	21.70	23.05	21.60	21.22	22.40	18.44	17.98	20.30	20.45	19.80	18.28	16.55	17.02	15.22	14.19
Fe_2O_3	2.21	0.83	2.49	2.89	3.19	3.05	4.51	3.05	2.60	4.16	3.27	3.36	2.57	1.82	1.07	2.15	1.37
FeO	4.67	6.18	5.04	5.88	5.39	4.23	2.46	4.40	5.29	4.37	4.48	4.55	4.80	3.90	4.40	3.59	2.12
MnO	0.04	0.09	0.03	tr	0.02	0.05	0.03	tr	0.03	tr	0.04	tr	0.04	0.04	0.02	0.07	0.02
MgO	2.04	3.42	2.98	1.60	1.99	2.68	1.08	3.40	3.28	1.29	2.81	1.58	2.26	0.60	1.92	0.60	0.31
CaO	1.26	1.32	2.21	0.80	1.73	0.65	2.09	0.99	2.46	0.64	0.84	tr	1.05	3.80	1.48	1.79	2.76
Na_2O	3.48	1.02	1.08	1.36	2.32	0.90	0.75	2.10	1.90	3.22	0.55	0.95	1.05	1.20	1.35	1.46	1.45
K_2O	5.72	6.81	4.22	5.10	4.00	4.63	5.25	4.06	3.90	3.55	3.75	3.80	2.92	3.70	4.25	3.72	2.50
H_2O	1.55	3.52	3.22	1.88	1.68	4.01	1.96	3.26	2.41	2.61	2.53	2.29	2.11	3.32	2.04	1.37	1.24
	100.02	99.83	100.04	100.43	100.29	100.06	100.26	99.61	100.05	100.36	100.03	100.32	99.82	99.93	100.33	100.28	100.29

Provenance and mineralogical composition of the analysed mica-schists

The first-mentioned minerals predominate; accessories have been omitted.

17 Arize — muscovite, biotite, oligoclase, quartz
18 Saint-Barthélemy — muscovite, biotite, quartz, oligoclase
19 Arize — muscovite, andalusite, biotite, quartz, oligoclase
20 Arize — biotite, muscovite, quartz, andalusite, cordierite, oligoclase
21 Arize — muscovite, biotite, cordierite, quartz, fibrolite, oligoclase
22 Trois Seigneurs — muscovite, biotite, quartz
23 Saint-Barthélemy — muscovite, andalusite, staurolite, biotite, quartz, oligoclase
24 Saint-Barthélemy — muscovite, biotite, quartz, oligoclase
25 Trois Seigneurs — biotite, andalusite, muscovite, quartz
26 Arize — biotite, muscovite, quartz, andalusite, cordierite, fibrolite
27 Trois Seigneurs — biotite, muscovite, andalusite, quartz, oligoclase
28 Saint-Barthélemy — muscovite, quartz, biotite, oligoclase
29 Arize — biotite, andalusite, quartz,muscovite, oligoclase
30 Arize — quartz, muscovite, biotite, oligoclase
31 Saint-Barthélemy — muscovite, quartz, biotite, oligoclase
32 Trois Seigneurs — quartz, cordierite, sillimanite
33 Saint-Barthélemy — quartz, muscovite, oligoclase

At the boundary the biotite is always very fine-grained and hardly discernable with the naked eye, but a few hundred metres deeper in this series the mica-schists are much coarser grained. Lineation as a result of micro-folding of the schistosity plane and stretching of micas is frequently present. Larger folds occur, but are only sparsely visible. Schistosity and bedding are often parallel, and sometimes it can be observed that the mica-schists are strongly isoclinally folded, but it is difficult to find the fold hinges.

The thickness of these mica-schists, which stands in no relation to any stratigraphic thickness, varies from a few hundred metres to several kilometres. This thickness depends on the position of the lower boundary: the migmatite front; when this front lies close under the Silurian slates, as for example near Trimouns (Saint-Barthélemy) the thickness of the mica-schists is very small, and phyllites are almost absent. When the migmatite front lies deep down in the Cambro-Ordovician, both mica-schists and phyllites have great thicknesses, as in the central part of the Arize massif. The higher the migmatite front rose to the surface, the greater is the temperature gradient above it and therefore the thinner the zone of mica-schists.

It is important to notice that the non-metamorphic cover above the biotite isograd can therefore be as thin as 2000 metres, the total thickness of the Paleozoic above the Cambro-Ordovician. With other words it has been proved here that the mesozone of regional metamorphism can rise as high as 2000 m below the surface.

Microscopically the following minerals have been observed in these mica-schists: biotite, muscovite, quartz and minor oligoclase. Accessories are the same as in the phyllites. Aluminum silicates do not occur, due to the low grade.

Andalusite mica-schists. — In the Trois Seigneurs massif and the largest part of the Arize massif andalusite mica-schists form a continuous zone below the biotite-muscovite schists. In the Saint-Barthélemy massif andalusite schists are only rarely present and the biotite-muscovite schists grade directly into the migmatites. We will discuss this difference in a separate paper on the metamorphic history.

The andalusite in these schists is often visible as large (up to 1 cm or more) porphyroblasts, but for the rest the megascopical properties of the rock are the same as in the biotite-muscovite schists. Besides the already mentioned minerals, cordierite has rather frequently been observed. In general the first occurrence of cordierite is somewhat deeper in the mica-schists than the first andalusites. Staurolite has been encountered in a several thin sections of the Arize massif and the Saint-Barthélemy massif. This mineral is very rare in the Trois Seigneurs massif. Kyanite has nowhere been found on this map sheet.

In the Arize massif the andalusite mica-schists grade into the migmatites, but in the Trois Seigneurs massif a sillimanite-bearing zone without andalusite and cordierite separates the andalusite schists from the migmatites. It is however doubtful whether this represents a new metamorphic zone, because the sillimanite, always present in the form of fibrolite, is not contemporaneous with the other aluminium silicates and the biotite, but is distinctly later and is probably related to the presence of pegmatites or to the contact metamorphism of the biotite-granodiorite. These sillimanite bearing schists have been represented on the map as normal mica-schists and not as a different zone.

Several chemical analyses of mica-schists have been executed in the petrochemical laboratory in Leiden, Table IV.

Lime-silicate gneisses. — Lime-silicate bands locally occur in the mica-schists of the Trois Seigneurs and Arize massif, but they are only abundant in the Saint-Barthélemy massif, where they are exposed particularly between the valleys of the Touyre and the Lasset. These lime-silicate gneisses are always sharply banded rocks with greenish, white, grey and red-brownish bands, dependent on the mineral association of such a band. In most cases this banding represents the sedimentary bedding. The original composition of these rocks is that of limy shales and marls.

The following minerals have been found in the lime-silicate gneisses: quartz, potash feldspar, andesine-labradorite, epidote-clinozoisite, green hornblende, biotite, diopside, titanite.

A chemical analysis of a lime-silicate gneiss from the Saint-Barthélemy massif shows the following composition, Table V.

TABLE V

Calc-silicate gneiss

Analysis no.	34	
SiO_2	63.00	
Al_2O_3	12.46	
Fe_2O_3	1.69	Quartz + feldspar 30 %
FeO	3.39	Epidote 35 %
MgO	3.37	Clinozoisite 10 %
MnO	0.05	Hornblende 20 %
CaO	9.43	Titanite acc. } 5 %
Na_2O	1.39	Diopside acc. } 5 %
K_2O	3.43	Apatite acc. } 5 %
TiO_2	1.04	
P_2O_5	0.38	
H_2O+	0.85	
H_2O-	0.13	
	100.61	

Migmatite — quartz-diorite series

The rocks belonging to this series have always transitional contacts with the overlying mica-schists. The migmatites and quartz-diorites are related by their mineralogical composition which always shows much aluminum silicates. There is an important difference in texture; on one hand there are migmatites and inhomogeneous gneisses, on the other hand almost completely homogeneous and unoriented quartz-diorites. Locally homogeneous biotite-gneisses and quartz-dioritic gneisses are exposed.

Quartz-dioritic gneiss. — In the Trois Seigneurs massif quartz-dioritic gneisses have been found near the boundary between mica-schists and migmatites. They are medium grained homogeneous gneisses with a mineralogical composition of quartz-diorite. Outcrops of these gneisses occur as elongated and conformable bodies with a maximum size of 2 km long and 200 m wide. The contacts with the enclosing mica-schists or migmatites can be sharp, but gradational contacts have also been observed. Sometimes the mica-schists become loaded with plagioclase porphyroblasts, thus producing a quartz-dioritic gneiss. Elsewhere the mica-schist contains sills of quartz-dioritic gneiss which increase in number, resulting in a gneiss with mica-schist septa. All these mica-schist—quartz-dioritic gneiss contacts are parallel with the schistosity.

Besides mica-schist septa inclusions of sillimanite-gneiss, marble and amphibolite occur also.

The quartz-dioritic gneisses have always a schistose and sometimes a linear texture. Crosscutting pegmatites are rather frequent.

The mineralogical composition of these gneisses is: quartz, plagioclase (andesine-labradorite) and biotite as main constituents, and garnet, orthite, zircon, apatite and ilmenite as accessories.

The contact relations and the occurrence of not disoriented inclusions indicate that these quartz-dioritic gneisses are feldspathized sediments. The rather calcium-rich composition of these gneisses makes it probable that the original sediment was a marly pelite (see Table VI).

For further details we refer to the thesis of Allaart (1958).

TABLE VI

Quartz-dioritic gneisses

Analysis no.	35	36
SiO_2	62.60	58.60
TiO_2	0.81	0.94
P_2O_5	0.12	0.09
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
H_2O	1.60	3.71
	100.18	100.44

35. Quartz-dioritic gneiss; Trois Seigneurs
36. Porphyroblast-schist near quartz-dioritic gneiss; Trois Seigneurs

Sillimanite-gneiss. — The sillimanite-gneisses are an important rock unit, which occurs in almost every gneiss massif of the Pyrenees. They are migmatites s.s., that means inhomogeneous gneisses consisting of quartzo-feldspathic layers alternating with mica-rich folia, containing biotite, sillimanite and muscovite. Typical is the unfoliated texture of the quartzo-feldspathic bands. These migmatites are very characteristic although there exists a great variety of rock types. The grain size can be rather large and in particular the biotite is often coarse-grained. Sillimanite is frequently visible as grey or silvery fibres, mostly associated with biotite. Muscovite is present as crystals of a few mm size.

The thickness of the sillimanite-gneisses varies with the area in which they occur. In the Saint-Barthélemy massif the total thickness amounts to several kilometres; in the eastern part of the Arize massif the sillimanite-gneisses are equally important, but westward there is a decrease in thickness down to a few hundreds of metres in the central part of the Arize massif. In the Trois Seigneurs massif also only some hundreds of metres of migmatites are present.

Towards the top the migmatites grade into mica-schists with a transitional

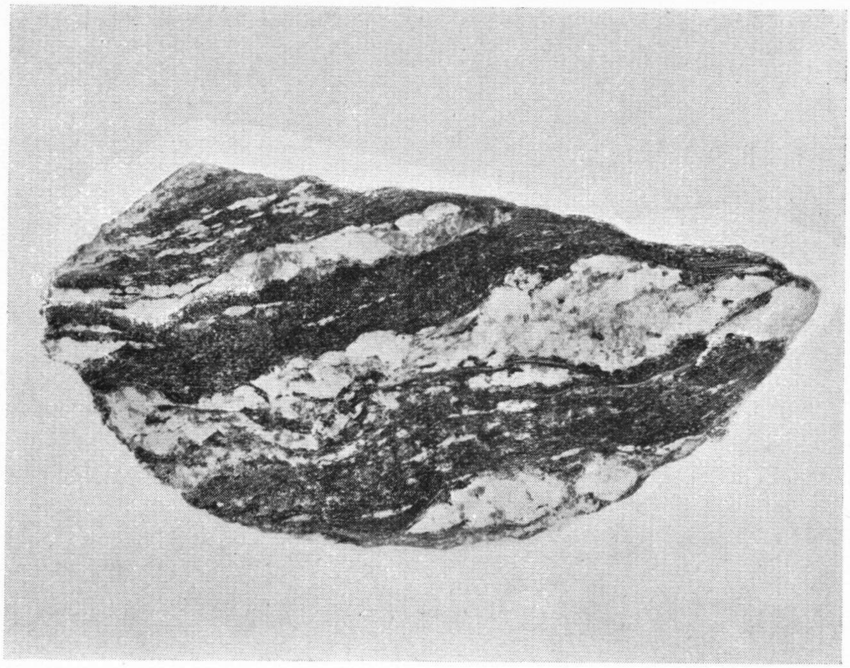

Fig. 9. Sillimanite-gneiss with boudinaged quartzo-feldspathic vein, Trois Seigneurs massif (after ALLAART).

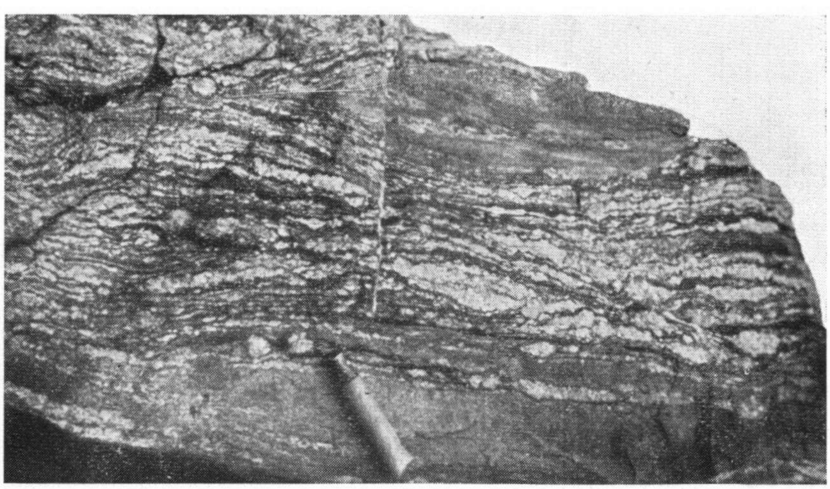

Fig. 10. Sillimanite-gneiss with boudinaged quartzite Trois Seigneurs massif.

zone of approximately 20—30 m thickness. Sometimes, however, the migmatites are overlain with a sharp boundary by a leucocratic gneiss or granite, which in its turn is covered by mica-schists, also with a sharp contact. In the Arize massif and the Trois Seigneurs massif the sillimanite-gneisses grade downwards into quartz-diorites. In the Saint-Barthélemy massif quartz-diorites occur as small or large masses in the middle of the sillimanite-gneisses. In this area the sillimanite-gneisses change downward into granitic gneisses (= gneiss à feldspath alcalin, ZWART 1954).

Although the sillimanite-gneisses are distinctly schistose, they seldom show any trace of lineation. Sometimes they are intricately folded and often the folding is of an irregular type with fold axes in variable directions.

Boudinage of the quartzo-feldspathic layers has been observed, but is not very common. The thickness of these layers is usually not greater than a few cm, but locally these bands are thicker and grade into conformable pegmatites. Although typical augen-shaped porphyroblasts have been observed in these gneisses, the quartzo-feldspathic layers and particularly the thicker ones, have an unoriented granitic texture. The whole rock is, however, distinctly folded.

Inclusions of mica-schists, quartzites, marbles and basic rocks, mainly amphibolites, occur frequently in the migmatites, in most cases as discontinuous bands.

Microscopically the sillimanite gneisses always show a constant mineral association of quartz, plagioclase (oligoclase), biotite, sillimanite (always as fibrolite associated with biotite) muscovite and often cordierite. The fibrolite replaces the biotite, whereas muscovite can replace biotite and fibrolite and is clearly the latest mineral in these gneisses. Sometimes potash feldspar is present, often as sparsely distributed large porphyroblasts. Cordierite is rather frequent in the migmatites. Accessories are zircon, apatite, tourmaline and ore. Table VII gives some analyses of the sillimanite-gneisses.

Quartz-diorites and nebulitic quartz-diorites. — The quartz-diorites and nebulitic quartz-diorites are always closely associated with the migmatites into which they gradually change. Undoubtedly there is a close genetic relation between these rocks.

In the Saint-Barthélemy massif quartz-diorites and nebulites occur as bodies in the sillimanite-gneisses, near the top as well as near the bottom. The size of these bodies is variable and can reach several hundreds of metres. They occur a. o. near the Pic du Saint-Barthélemy. In these quartz-diorite outcrops inclusions of sillimanite-gneisses are frequent, always with gradational contacts.

In the Arize and Trois Seigneurs massif the quartz-diorites and nebulites form an important continuous zone below the sillimanite-gneisses, and in fact they are the deepest exposed rock units in these areas, with the exception of the eastern part of the Arize massif and possibly some gneisses near Lapège in the Trois Seigneurs massif. The maximum thickness of these quartz-diorites and nebulites amounts to 4000—5000 metres. In particular the Trois Seigneurs massif is the area where these rocks are exposed over large surfaces. They have been elaborately described by ALLAART (1958).

One of the most striking features of the quartz-diorites especially in the Trois Seigneurs massif, but to a less degree also in the two other areas, is the mobilization or rheomorphism, which has influenced these rocks in a certain stage of their recrystallization. This mobilization results not only in

TABLE VII

Sillimanite-gneisses

Analysis no.	37	38	39	40	41	42	43	44	45	46
SiO_2	51.55	56.84	57.28	57.86	58.01	59.80	60.60	62.14	62.57	66.00
TiO_2	1.21	1.11	1.31	0.98	0.93	1.38	1.10	1.42	1.03	0.67
P_2O_5	0.22	0.26	0.13	0.14	0.19	0.06	0.12	0.08	0.23	0.14
Al_2O_3	23.50	23.65	20.40	22.50	20.70	16.98	18.52	16.20	18.69	16.30
Fe_2O_3	4.32	2.64	3.74	1.49	2.44	1.68	2.09	1.74	0.33	1.57
FeO	4.23	3.39	5.89	4.09	3.73	5.58	3.47	5.93	5.30	3.63
MnO	0.16	0.13	0.04	0.07	0.14	0.06	0.11	0.09	0.10	0.07
MgO	2.01	0.99	3.22	4.06	3.50	2.96	1.93	2.65	3.13	2.60
CaO	3.92	3.52	0.88	1.21	2.80	2.30	2.36	1.79	1.73	1.72
Na_2O	1.85	1.70	1.25	2.10	3.00	1.60	1.60	1.26	1.79	2.50
K_2O	4.39	4.50	3.58	3.50	3.42	5.50	5.40	4.70	3.51	2.68
H_2O	2.65	1.54	2.33	2.24	1.23	1.96	2.44	1.76	1.56	2.50
	100.01	100.27	100.05	100.24	100.09	99.86	99.74	99.76	99.97	100.38

Provenance and mineralogical composition of the analysed sillimanite-gneisses.

(The accessories have been omitted)

37. Saint-Barthélemy — quartz, oligoclase, biotite, sillimanite, muscovite.
38. Saint-Barthélemy — quartz, oligoclase, biotite, muscovite, sillimanite.
39. Arize — quartz, oligoclase, cordierite, biotite, muscovite, sillimanite.
40. Saint-Barthélemy — quartz, oligoclase, potash feldspar, biotite, muscovite, sillimanite.
41. Saint-Barthélemy — quartz, oligoclase, potash feldspar, biotite, sillimanite, cordierite, muscovite.
42. Saint-Barthélemy — quartz, oligoclase, cordierite, biotite, sillimanite, muscovite.
43. Saint-Barthélemy — quartz, oligoclase, biotite, cordierite, muscovite, sillimanite.
44. Saint-Barthélemy — quartz, oligoclase, potash feldspar, biotite, sillimanite, muscovite.
45. Saint-Barthélemy — quartz, oligoclase, biotite, sillimanite, muscovite.
46. Trois Seigneurs — quartz, oligoclase, biotite, sillimanite, muscovite.

TABLE VIII

Quartz-diorites

Analysis no.	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
SiO_2	57.50	59.58	60.20	60.75	61.70	63.25	63.78	64.72	64.85	64.85	65.86	67.64	68.60	69.28	69.40	70.10
TiO_2	1.04	1.11	0.89	0.94	0.80	0.52	0.63	0.19	0.65	1.02	0.60	0.54	0.60	0.56	0.49	0.39
P_2O_5	0.24	0.22	0.24	0.57	0.23	0.25	0.23	0.91	0.18	0.14	0.27	0.24	0.26	0.12	0.15	0.07
Al_2O_3	17.90	19.51	19.55	18.23	17.88	17.62	17.72	15.25	16.95	15.73	16.25	16.96	14.30	14.69	15.72	16.34
Fe_2O_3	0.28	2.69	1.81	0.71	1.38	1.03	1.28	2.37	2.49	2.37	1.90	1.67	0.81	0.65	3.48	1.01
FeO	4.82	4.58	4.71	3.48	3.57	3.23	2.99	3.49	2.89	3.33	3.22	1.98	2.76	2.51	1.51	1.80
MnO	0.07	0.04	0.04	0.10	0.02	0.02	0.02	0.08	0.03	0.09	0.09	0.03	0.04	0.04	0.03	0.08
MgO	6.67	2.76	2.44	1.62	2.47	2.14	2.12	3.04	1.76	2.13	3.04	0.61	1.76	1.38	2.07	0.30
CaO	3.26	1.39	1.78	4.91	3.52	4.09	3.35	2.17	1.36	1.96	1.56	1.74	2.53	2.02	1.04	2.28
Na_2O	2.30	2.32	3.22	4.52	2.87	2.77	2.95	2.55	2.96	3.52	2.68	3.36	2.55	3.71	2.58	5.10
K_2O	3.90	3.59	3.40	3.44	3.45	3.04	3.02	3.21	4.15	3.34	3.38	3.92	4.57	3.52	2.16	1.92
H_2O	1.70	1.75	1.60	0.71	1.74	1.76	1.62	1.74	1.72	1.29	1.27	1.14	1.18	1.26	1.32	0.61
	99.68	99.54 + 0.46% insoluble	99.88	99.98	99.63	99.72	99.71	99.72	99.99	99.74	100.12	99.83	99.96	99.74	99.95	100.00

Provenance and mineralogical composition of the analysed quartz-diorites.

(The accessories have been omitted)

47. Saint-Barthélemy — quartz, oligoclase, biotite, sillimanite, muscovite.
48. Arize — quartz, oligoclase, biotite, sillimanite, muscovite, cordierite.
49. Arize — quartz, oligoclase, biotite, sillimanite, muscovite.
50. Trois Seigneurs — quartz, oligoclase, potash felspar, biotite, muscovite, sillimanite.
51. Trois Seigneurs — quartz, oligoclase, potash felspar, biotite, cordierite, muscovite.
52. Trois Seigneurs — quartz, oligoclase, biotite, muscovite.
53. Trois Seigneurs — quartz, oligoclase, potash felspar, biotite, muscovite.
54. Saint-Barthélemy — quartz, oligoclase, biotite, sillimanite, muscovite.
55. Arize — quartz, oligoclase, biotite, cordierite, sillimanite, muscovite.
56. Trois Seigneurs — quartz, oligoclase, biotite, muscovite, potash felspar.
57. Saint-Barthélemy — oligoclase, quartz, biotite, sillimanite, muscovite.
58. Arize — quartz, oligoclase, potash felspar, biotite, muscovite.
59. Trois Seigneurs — quartz, oligoclase, potash felspar, biotite, muscovite.
60. Trois Seigneurs — quartz, oligoclase, potash felspar, biotite, muscovite.
61. Arize — quartz, oligoclase, potash felspar, biotite, muscovite, sillimanite.
62. Trois Seigneurs — quartz, oligoclase, potash felspar, biotite, muscovite.

the occurrence of flow structures but also in a strong disorientation of the numerous inclusions (see fig. 11 and 12). On the other hand the quartz-diorites did not become intrusive and they still occur on the place where they have been formed. These features are excellently exposed in the steep cliffs near lake Artax in the Trois Seigneurs massif and a visit to these outcrops does not leave any doubt as to the existence of this mobilization.

The quartz-diorites and nebulitic quartz-diorites are medium-grained rocks with unoriented texture. Although a handspecimen can be completely homogeneous, a whole outcrop always shows irregularities. Sparsely distributed large porphyroblasts of potash feldspar and elongated biotite schlieren and patches are the main cause of this inhomogeneity. These patches and schlieren lie mostly parallel and flow structures are often visible by the arrangement of these biotite concentrations.

In the Saint-Barthélemy massif more basic quartz-diorites occur, which have no muscovite and sillimanite, but contain more basic plagioclase, andesine or labradorite, and sometimes hornblende (see Table XII). These rocks presumably have formed at the expense of original calcareous pelites. They grade into normal aluminum rich quartz-diorites and sillimanite-gneisses.

The mineralogical composition of the quartz-diorites and nebulites is: quartz, plagioclase (oligoclase), biotite, muscovite, sillimanite and often potash feldspar and cordierite. The first five of these minerals are contemporaneous; potash feldspar, which always is a minor constituent, is later and replaces the other minerals. Muscovite is the latest mineral and replaces on its turn potash feldspar and also quartz, biotite and plagioclase. At the same time cordierite is sometimes replaced by phlogopite and muscovite. Accessories are apatite, zircon, garnet, tourmaline, orthite and ilmenite. For the chemical composition see Table VIII.

Homogeneous biotite-gneiss. — In the Trois Seigneurs massif and also in the Saint-Barthélemy massif homogeneous biotite-gneisses occur in the quartz-diorites and sillimanite-gneisses. They are closely related to these rocks and often have the same mineralogical composition. The only difference is then the texture, which is gneissose but homogeneous. More basic biotite gneisses and even hornblende-bearing gneisses are also present, particularly in the Saint-Barthélemy massif. Their original rocks were somewhat richer in calcium than the pure pelites. The contacts with the quartz-diorites and sillimanite-gneisses are always transitional. They occur more frequently than is indicated on the map.

In the Trois Seigneurs massif several kinds of homogeneous biotite-gneisses have been mapped. Linear muscovite-biotite gneisses occur as layers in the sillimanite-gneisses, often with sharp contacts. They are quite similar to the linear augengneisses, but they are distinctly recrystallized. Elsewhere more basic biotite gneisses show transitions to the migmatites. Mineralogically their composition is the same as these gneisses, although they are somewhat more leucocratic. Garnet-bearing gneisses occur between Lapège and Junac with sharp or transitional boundaries in migmatites or quartz-diorites. Locally these gneisses are linear and sometimes finely banded; also feldspar augen have been observed. Mineralogically these gneisses show similarity to the garnet-bearing augengneisses of the Saint-Barthélemy massif. Since they also occur in the lower part of the metamorphic series of the Trois Seigneurs massif this correlation may be correct. The gneisses near Lapège are, however, strongly influenced by post-kinematic recrystallization in contrast with the garnet-augen-

Fig. 11. Displaced and rotated inclusions (diopside-gneiss) in mobilized quartz-diorite; Saint-Barthélemy massif (after ZWART).

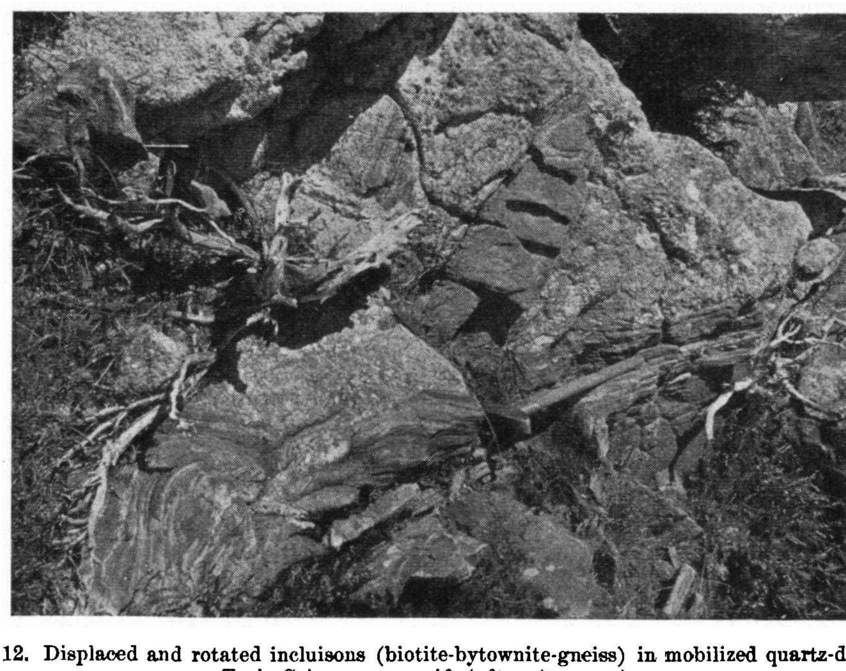

Fig. 12. Displaced and rotated incluisons (biotite-bytownite-gneiss) in mobilized quartz-diorite, Trois Seigneurs massif (after ALLAART).

gneisses in the Saint-Barthélemy massif which are purely synkinematic. For further details of these homogeneous biotite gneisses in the Trois Seigneurs massif we refer to the publication of ALLAART (1958).

Basal gneiss series

Rocks belonging to this series occur only in the Saint-Barthélemy massif and the eastern part of the Arize massif. They underlie the migmatites and quartz-diorites with a boundary which is transitional structurally as well as mineralogically and chemically. In the E and W part of the Saint-Barthélemy massif and the E part of the Arize massif the basal gneisses are separated from the overlying rocks by a fault, but in the central part of the Saint-Barthélemy massif exists a complete, undisturbed series from basal gneisses to the migmatites.

These rocks have been described as "vieux paragneiss" (ZWART 1954) and were originally supposed to be unconformably covered by the migmatites, thus representing an older orogenic cycle. This opinion was mistaken as has correctly been pointed out by GUITARD (1955). Rocks similar to these basal gneisses seem to be restricted to the north-Pyrenean massifs (Agly, Arize, Saint-Barthélemy, Castillon).

From top to bottom the following stratigraphical subdivision can be made:

1) Granitic biotite-muscovite gneiss
2) Linear garnet augengneisses, with intercalated folded augengneisses
3) Schistose garnet-bearing granitic gneiss
4) Granite and gneissose granite, often leucocratic.

These zones run from one end to the other in the Saint-Barthélemy massif over a distance of more than 15 km, but the thickness of the different units varies. In the eastern part of the Arize massif the same zoning can be observed. This zoning represents an excellent example of the splitting up of a gneiss series in layers with similar composition and metamorphic history and will be summarized in another chapter.

Granitic biotite-muscovite gneiss (= gneiss à feldspath alcalin, ZWART 1954). — These rocks, which have been described as the basal part of the migmatite series (ZWART 1954), are in every sense a transitional member between the migmatites and the augengneisses, respectively lying above and below these granitic gneisses. This transition is of structural as well as mineralogical nature.

The granitic gneisses are in general much more homogeneous than the migmatites. They often have a rather granitic and melanocratic appearance, although they contain less dark minerals than the migmatites. Nebulitic rocks are of frequent occurrence especially near the boundary with the migmatites. Sometimes large, more or less isolated feldspar augen have been observed in these rocks. Very typical are rounded feldspar crystals of a size of approximately 2—3 mm surrounded by biotite. Toward the lower boundary the gneissose character becomes more distinct and a faint linear texture, visible as a striping on the schistosity plane, can sometimes be seen. This lineation plunges with a small angle to the north.

Intricate folding and rock flowage like in the sillimanite-gneisses do not occur in the granitic gneisses. The numerous inclusions, frequently amphibolites, which can be found in these gneisses, are never disoriented.

The mineralogical composition of these gneisses is quartz, oligoclase, potash feldspar, biotite, muscovite, sillimanite and sometimes cordierite and garnet. The boundary with the underlying augengneisses has been drawn, where megascopically no more muscovite is present. This boundary is quite useful, since with the disappearance of the muscovite also certain properties of the gneisses, the occurrence of typical feldspar augen for example, become prominent.

Garnet-augengneisses. — The garnet-bearing augengneisses are one of the most peculiar rocktypes in the map-area. The most striking feature is the structure of these rocks, which shows always augen of feldspar, cordierite or even garnet, around which the other constituents, quartz and biotite are arranged in a flow-like fashion. This structure is entirely independent of the grainsize of the minerals. The augen can vary in size from ½ mm to 10 cm. Nearly always these augen consist of plagioclase or potash feldspar, but also beautiful cordierite and garnet augen have been observed. Both under the microscope and in the outcrops this augentexture is very striking.

Besides a distinct foliation, the augengneisses always show an evident lineation (see fig. 13). This lineation, which is visible on the schistosity plane as a remarkable striping, is mainly caused by the shape of the augen, which in most cases have a different shape in three perpendicular directions. They are more or less flat spindle shaped with an elongation in the direction of the lineation. Locally these augen have in two directions, perpendicular to the lineation, an equidimensional shape, or in other words they are round rods lying in the direction of the lineation. A schistosity is in this case absent: these rocks are pure B-tectonites [2]). They occur for example near Caussou. More often, however, the gneisses are S-B-tectonites, which means that besides a lineation, a distinct schistosity plane is present. The plunge of the lineation, which is strictly parallel in the whole Saint-Barthélemy massif, is N, parallel to the lineation in the granitic gneisses. This is an excellent proof of the conformable character of both rocktypes, in contrast with an earlier supposed unconformity.

These augengneisses are often banded: light coloured aplitic or pegmatitic bands alternate with dark biotite-garnet bearing bands. The thickness of these various layers is in general not more than 10 cm. Structurally these aplitic and pegmatitic layers are identical with the normal gneisses, because in these bands too feldspar augen occur around which quartz is present as mylonitic zones. Gneisses with large augen and aplitic bands have also been observed. When a large eye occurs close to such a band, this band is always pushed aside by the eye. Rarely the pegmatitic bands are boudinaged.

Layers of basic rocks, mainly amphibolites, are frequently present in the augengneisses, always as conformable layers and sometimes boudinaged. It is important to note, that in these gneisses never any crosscutting element has been found. All structural elements are parallel and have the same schistosity and the same lineation.

Only once a sharp isoclinal folding of an original sedimentary stratification or of an old metamorphic banding has been observed.

Microscopically the following minerals are present; quartz, plagioclase

[2]) The lineation is called a b-lineation, since they are parallel with fold axes. It is not excluded that it concerns in reality a-lineations, as their N—S direction is perpendicular to the general E—W strike of the Hercynian orogene.

(albite or sodic oligoclase) potash feldspar (untwinned microcline or microperthite), biotite, garnet, cordierite and sillimanite. The two last mentioned minerals are not always present; sometimes a little muscovite occurs. The augen are porphyroblasts to porphyroclasts around which biotite and quartz occur as sheared crystals. Often even a mylonitic texture prevails. In the pegmatitic and aplitic bands without biotite, only quartz is present as strongly sheared zones around the feldspar-augen.

The thickness of the augengneisses together with the folded augengneisses amounts at most to approximately 1500 m, but to the west the thickness decreases to no more than a few hundred metres.

Fig. 13. Linear garnet augengneiss; hammer lies on plane normal to lineation Saint-Barthélemy massif.

Folded garnet augengneisses. — In many respects the folded garnet augengneisses have the same properties as the normal garnet augengneisses and in fact the only difference is that the schistosity of these gneisses is not straight, but clearly folded. These folds are quite regular and have an amplitude of approximately 5—20 cm. They are in most cases more or less concentric, sometimes with incipient S_2 planes in the limbs, often marked by the occurrence of coarser grained feldspar. Rather narrow folds also are present but they never become isoclinal. When aplitic or pegmatitic bands occur, these are folded together with the gneisses (see fig. 14). Separate feldspar augen also can be folded. The fold axes of the gneisses all have the same direction and plunge, and are always parallel to the lineation, indicating that folding and the formation of the lineation are related features. The folded augengneisses run in a zone parallel to the general zoning in these basal gneisses. They are, however, absent in the eastern and western part of the Saint-

Barthélemy massif. The thickness of these folded augengneisses amounts to a maximum of 600 metres.

We want to emphasize, that this picture of folding is completely different from that of the migmatites, in which a more or less unarranged rock flowage prevails, which is contrasted to the strong parallel arrangement of fold axes and lineations in the augengneisses.

Schistose garnet-bearing gneiss. — Structurally downward the augengneisses change in character in such a way that the strong lineation and typical feldspar augen disappear, resulting in a rather homogeneous, but still schistose gneiss. Locally a faint lineation can be visible and also folding of the schistosity has occasionally been observed. In both cases the lineation and fold axes run parallel to these elements in the overlying augengneisses. The mineralogical composition is identical with the augengneisses, but some mus-

Fig. 14. Folded garnet augengneiss with leucocratic bands; Saint-Barthélemy massif.

covite can be present, whereas the garnets are often partially altered into biotite. In the extreme eastern part of the Saint-Barthélemy massif these gneisses are not exposed, because they are cut off by the north-Pyrenean fault and overlain by Mesozoic sediments. In the eastern part of the Arize massif these gneisses occur also and are a. o. exposed in the railroad cuts between Bompas and Tarascon.

Granite and gneissose granite. — The deepest exposed part of the Saint-Barthélemy massif consists of rather coarse grained, mostly unoriented rocks. Sometimes these rocks are granitic, but often they have a faint gneissose structure. Frequently these granites and granitic gneisses are quite inhomogeneous and sometimes more or less migmatitic, although they are distinctly different from the sillimanite-gneisses. Often these rocks are rather leuco-

TABLE IX

Granitic biotite-muscovite-gneisses

Analysis no.	63	64	65	66	67	68	69	70
SiO_2	63.98	64.30	64.50	65.20	66.80	67.25	71.96	73.62
TiO_2	0.88	0.97	1.07	0.81	0.66	0.75	0.36	0.24
P_2O_5	0.19	0.31	0.37	0.24	0.34	0.18	0.28	0.19
Al_2O_3	17.02	15.95	16.42	16.00	15.90	15.21	15.23	12.11
Fe_2O_3	3.67	2.83	1.72	2.17	2.18	1.77	0.26	1.86
FeO	2.57	3.55	3.84	3.43	2.14	3.00	1.89	1.58
MnO	0.03	0.04	0.04	0.04	0.03	0.03	0.04	0.08
MgO	2.08	1.98	1.93	2.49	0.56	1.88	0.47	0.63
CaO	2.34	2.60	2.85	1.58	3.49	2.37	1.93	1.39
Na_2O	2.72	2.94	2.68	2.57	3.32	2.62	2.96	2.60
K_2O	2.30	2.50	3.28	3.96	3.38	3.50	3.75	4.72
H_2O	2.34	1.85	1.46	1.63	1.15	1.43	0.78	0.87
	100.12	99.82	100.16	100.12	99.95	99.99	99.91	99.89

Provenance and mineralogical composition of the analysed granitic biotite-muscovite-gneisses

(accessories have been omitted)

63. Saint-Barthélemy — potash feldspar, oligoclase, quartz, biotite, muscovite, sillimanite, cordierite.
64. „ — oligoclase, quartz, biotite, muscovite, sillimanite.
65. „ — potash feldspar, oligoclase, quartz, biotite, muscovite, sillimanite.
66. „ — potash feldspar, oligoclase, quartz, biotite, muscovite, sillimanite.
67. „ — oligoclase, potash feldspar, quartz, biotite, sillimanite, muscovite.
68. „ — oligoclase, potash feldspar, quartz, biotite, sillimanite, muscovite.
69. „ — potash feldspar, oligoclase, quartz, biotite, muscovite, sillimanite.
70. „ — potash feldspar, oligoclase, quartz, biotite, muscovite, garnet, sillimanite.

TABLE X

Garnet-augengneisses

Analysis no.	71	72	73	74	75	76	77	78	79	80
SiO_2	58.40	65.85	66.25	67.85	68.40	68.64	69.74	69.80	70.40	71.70
TiO_2	1.46	0.84	0.80	0.86	0.76	0.68	0.63	0.82	0.71	0.30
P_2O_5	0.03	0.51	0.35	0.19	0.21	0.20	0.39	0.29	0.29	0.31
Al_2O_3	17.82	16.80	16.08	14.22	13.90	14.28	13.81	13.72	15.04	14.85
Fe_2O_3	3.97	2.50	3.05	1.47	3.31	2.67	0.88	2.60	2.26	1.21
FeO	6.81	2.16	2.14	3.86	1.90	1.92	2.80	2.38	0.53	0.89
MnO	0.04	0.04	0.03	0.03	0.02	0.02	0.03	0.02	0.01	0.02
MgO	2.17	1.36	1.55	1.14	0.78	1.44	1.22	0.98	0.56	0.62
CaO	3.20	2.05	2.46	2.12	2.56	2.17	2.80	1.90	1.59	1.49
Na_2O	1.70	3.40	3.40	3.02	3.78	3.89	3.78	3.10	3.05	2.98
K_2O	2.61	3.68	3.38	3.95	3.44	3.05	3.24	3.32	4.90	4.80
H_2O	1.73	0.83	0.56	1.21	1.22	1.05	1.14	0.89	0.73	0.59
	99.94	100.02	100.05	99.92	100.28	100.01	100.46	99.82	100.07	99.76

Provenance and mineralogical composition of the analysed garnet-augengneisses

(the accessories have been omitted)

71. Saint-Barthélemy — oligoclase, quartz, biotite, cordierite, garnet, sillimanite, potash feldspar.
72. „ — oligoclase, potash feldspar, quartz, biotite, sillimanite, garnet.
73. „ — oligoclase, potash feldspar, quartz, biotite, garnet.
74. „ — potash feldspar, oligoclase, quartz, biotite, garnet.
75. „ — potash feldspar, oligoclase, quartz, biotite.
76. „ — potash feldspar, oligoclase, quartz, biotite.
77. „ — oligoclase, potash feldspar, quartz, biotite, garnet.
78. „ — potash feldspar, oligoclase, quartz, biotite, garnet.
79. „ — potash feldspar, oligoclase, quartz, biotite.
80. „ — potash feldspar, oligoclase, quartz, biotite, sillimanite, muscovite.

cratic as for example is the case in the outcrops near Cazenave along the road to Arnave. Somewhat closer to Arnave, however, more melanocratic biotite and cordierite-bearing gneisses are present. Locally typical augengneisses occur. The outcrops of the granitic gneisses and granites are frequently more or less mylonitized as a result of movements along the north-Pyrenean fault, which forms the southern boundary of these rocks.

A remarkable feature are the marbles and lime-silicate rocks, which are widespread in this zone, and probably form an original stratigraphical horizon. These calc-silicate gneisses and marbles occur for example near Cazenave, between Arnave and Cazenave, between Cazenave and Senconac, near Caychax, Appy and Axiat.

The mineralogical composition of these granites and gneissose granites is quartz, sodic plagioclase (albite-oligoclase), potash feldspar, biotite and locally garnet and little muscovite. Plagioclase always predominates over potash feldspar. Garnet is often altered along cracks into biotite or light green phlogopite.

Eight analyses of the granitic biotite-muscovite gneisses and ten of garnet-augengneisses have been executed (see table IX and X).

Muscovite-granite and gneiss series

Although various members of this group are different, both in history and in character, their mineralogical and chemical composition and their mutual relations as well as relations to their host rock indicates that all these gneisses and granites are closely connected.

In the first stages of our investigation the opinion prevailed that all these rocks are intrusive granites, partially gneissified and older, and for the rest undeformed and later than the hercynian folding. Many arguments induced as, however, to change this idea in favour of a replacement origin for most of these rocks.

In principle two types can be distinguished: 1) gneisses which have undergone a syn- and a post-kinematic metamorphism and in which both stages are visible, and 2) granites which are post-kinematic: the muscovite-biotite-granites. An intermediate stage is represented by the muscovite-biotite granitic gneiss, which probably is late-kinematic. Further a great number of pegmatites can be classified in this group. Most of the pegmatites are late- or post-kinematic.

A remarkable property of these rocks is that they nearly always occur quite high in the metamorphic series. Often they are emplaced between the migmatites and mica-schists. Sometimes they occur in the mica-schists or somewhat below the mica-schist-migmatite contact. Occasionally they occur deeper in the metamorphic series as for example in the Arize massif, but in that case we deal with small bodies.

Muscovite- and muscovite-biotite-granite. — Granites of this type occur in the Trois Seigneurs and Arize massif. In the Trois Seigneurs massif two stocks have been mapped, one in the valley of the Courtignou, the La Ruse granite, and the other near Pic d'Estibats. The first one is a homogeneous biotite-muscovite-granite, which is considered as an intrusive body by NIEUWENHUYS (1956) and ALLAART (1958). This conclusion is based on a sudden deviation of the schistosity of the enclosing mica-schist near the contact with the granite. This results in an always conformable contact between both rocks and is considered as adequate proof for the pushing aside of the wall rock and hence in emplacement by intrusion. The contacts are always sharp.

In the central part of the granite a large outcrop of mica-schist is present, probably a part of the roof of the stock.

Mineralogically the granite consists of quartz, albite or oligoclase, microcline, muscovite and biotite. Accessories are apatite, zircon and ore.

The granite of the Pic d'Estibats is in many respects similar to the granite of La Ruse, but is considered by ALLAART as a replacement granite. It is a muscovite-granite lying in the mica-schists immediately above the migmatite boundary. This granite contains several not disoriented septa of mica-schist and sillimanite-gneiss. The contacts are always conformable.

A body of a somewhat different rock occurs S of the Pic de Pioulou. This rock consists of a leucocratic quartz-diorite and contains no potash feldspar.

In the Arize massif several sills and bodies of muscovite-granite occur, mainly in the upper part of the migmatite series. Only the most important sills have been recorded on the map; many smaller ones have been omitted. The contacts of these granites with the adjacent rocks are always sharp and often conformable. Remnants of migmatites have sometimes been found in these granites; they are never disoriented. The granites are very leucocratic, medium-grained rocks, which occasionally show a faint schistosity. Biotite is only seldom present. Mineralogically these Arize granites are very similar to the muscovite-granites of the Trois Seigneurs massif. They always contain quartz, sodic plagioclase, microcline and muscovite as main constituents.

Muscovite-biotite granitic gneiss. — In the southern part of the Trois Seigneurs massif, south of Etang d'Arbu a leucocratic gneiss occurs as large boudin-shaped masses in mica-schists, which lie close above the migmatite front. The size of these "boudins" amounts to 400 m long and 50 m thick. The mineralogical composition is approximately the same as that of the muscovite-biotite-granites, but the structure is definitely gneissose. The contacts with the mica-schists are rather sharp, but bands and schlieren of mica-schists are locally present in the gneiss close to the contacts. These inclusions have always the same strike and dip as the surrounding mica-schists and consequently are not disoriented. The structure of these gneisses is not usually linear and differs from that of the augengneisses. This is also clear in thin section, which shows an almost entirely unoriented structure and an intergrowth of the minerals similar to that of the granites. The mineralogical composition of these granitic gneisses is quartz, sodic plagioclase, microcline, muscovite and biotite, with apatite, zircon and ore are accessories.

In the eastern part of the Arize massif north of Amplaing and Mercus a very leucocratic gneissose granite occurs, which microscopically is also little oriented. These gneisses have very little micas and consist entirely of quartz, albite and microcline.

Linear muscovite-augengneiss. — In the Saint-Barthélemy massif a continuous zone of locally linear augengneisses runs from the E to the W side of this area. Megascopically these gneisses are structurally identical with the garnet augengneisses, although the lineation is often not so pronounced.

The boundaries with the adjacent rocks are always sharp. Locally elongated mica-schist inclusions, parallel to the schistosity, occur in the gneiss. Basic rocks or marbles have not been found. The muscovite-augengneiss often lies as a big sill between migmatites below and mica-schists on top of it. East of the Touyre, however, migmatites also were found above the gneiss.

Megascopically this gneiss varies from place to place; for example the colour can change from white to medium gray, dependent on the biotite content; de grain-size is variable, although mostly medium grained rocks prevail. The augenshaped feldspars have a size of approximately 2—3 mm.

West of Trimouns these gneisses are extremely sheared and mylonitized by later movements.

An extension of this gneiss sill is present in the eastern part of the Arize massif in a small exposure along the road from Foix to Tarascon E of the Ariège and a larger outcrop near Prayols W of the Ariège. This gneiss has rather large feldspar augen up to a size of several cm. Locally this augengneiss character is less pronounced.

A similar augengneiss, also coarse grained occurs in the Aston massif, of which a small part is represented on the map.

The mineralogical composition of these augengneisses is similar to that of the muscovite-biotite-granites, viz. quartz, albite-oligoclase, potash feldspar (microperthite or microcline), muscovite and biotite as main constituents, and apatite, zircon, tourmaline and ore as accessories. Aluminium silicates have not been found. The microscopical structure of these augengneisses, however, is different from that of the garnet bearing augengneisses. A pronounced deformation structure as in the latter is not present, because often the feldspar-augen are replaced by a fine-grained intergrowth of quartz and feldspar. This replacement structure is of post-kinematic age and for this reason the muscovite-augengneisses are no pure synkinematic rocks as the garnet-augengneisses.

Linear muscovite-augengneiss with euhedral feldspar porphyroblasts. — A particular rock type, occurring in the muscovite-augengneisses of the western part of the Saint-Barthélemy massif, has been found a few hundred m N of Trimouns, which continues to the Lasset valley, and S of Trimouns near the fault with the underlying augengneisses. This rock is the same augengneiss but it contains numerous euhedral potash feldspar porphyroblasts. The tabular crystals often lie in the schistosity plane or in the lineation. These porphyroblasts are much larger than the augen and reach a length of 2 cm and a thickness of ½ cm.

Microscopically the porphyroblasts consist of microperthite or microcline with Carlsbad twinning.

Pegmatites. — Pegmatites are of frequent occurrence, especially in the migmatites and mica-schists. Conformable and unconformable pegmatites are equally well represented. In general the pegmatites have an unoriented granitic texture. Often there is an evident structural control for their emplacement for example pegmatites between boudins, in saddle reefs of folds etc. The pegmatites themselves can also be boudinaged, whereas folded pegmatites have also been observed. In general the pegmatites have sharp contacts with the enclosing rocks, but pegmatites of a rather vague shape and with diffuse contacts have also been observed.

Genetically they can be divided in pegmatites which have been influenced by deformation, for instance folded pegmatites, boudinaged pegmatites, and those which are later than the period of folding, mostly crosscutting pegmatites. Most of the pegmatites have not been recorded on the map, because they are too small and too numerous; only the largest ones are represented.

Four chemical analyses have been executed from rocks of the muscovite-granite and gneisses series (Table XI).

Talc-chlorite rocks

Talc deposits of economic importance occur in the Saint-Barthélemy massif. This mineral is worked in the quarries of Trimouns and Porteille. The talc-chlorite rocks are produced by silica metasomatism on the Cambro-Ordovician dolomite. For further details we refer the reader to chapter 5 on the economic deposits.

Metamorphic marbles (cipolins)

Metamorphic marbles and associated calc-silicate rocks occur on many places in the gneisses and mica-schists. In most cases they are present as rather small outcrops, but on several localities in the map area important marbles have been found in the gneisses and migmatites. Partly these marbles have already been described, for example the famous marbles of Arignac by LACROIX (1890). Near this village in the Arize massif a marble zone occurs which can be followed over a distance of 4000 m. Many interesting minerals from this outcrop have been mentioned by LACROIX, for example humite, spinel, phlogopite, scapolite, diopside, etc. Most of these minerals have again been found by us, although not in such beautiful specimens have been described by LACROIX. The continuation of this zone east of the Ariège near Mercus, which formerly was exposed in a quarry, now only can be seen in a brush-covered slope.

Another large marble outcrop occurs in the Trois Seigneurs massif along the road Junac-Lapège. These marbles are sharply banded and alternate with lime-silicate gneisses. They are locally pink coloured. The most important minerals are diopside, plagioclase, epidote, phlogopite, green hornblende.

In the southern part of the Saint-Barthélemy massif a discontinuous marble and lime-silicate zone occurs in the deepest exposed granitic gneisses. The rocks are characterized by the occurrence of diopside, basic plagiolase, green hornblende, clinozoisite and calcic scapolite.

Many other small marble outcrops are scattered in the gneisses and migmatites. Their mineralogical composition and metamorphic history will be dealt with in a separate publication, appearing in this issue.

The frequent occurrence of these marble and lime-silicate bands in the gneisses and migmatites is excellent proof for their original sedimentary character.

A few chemical analyses of calc-silicate rocks can be found in Table XII.

Amphibolites

Although many amphibolites are associated with the marbles and lime-silicate rocks and as such are not separately recorded on the map, those amphibolites which have been found as independent bodies are represented with a different colour. Only a few amphibolites were large enough to be mapped separately. Many others occur in all sorts of gneisses as small inclusions. Although definite proof cannot be given, it is assumed that a part of these independent amphibolites are of igneous origin. Those amphibolites which are associated with marbles are most probably of sedimentary origin.

The amphibolites are dark green or black, rather fine-grained rocks, in which a linear texture, caused by the parallel arrangement of hornblende crystals, is clearly visible. They are often present as boudin-shaped inclusions in the gneisses.

TABLE XI

Muscovite-gneisses and granites

Analysis no.	81	82	83	84
SiO_2	68.23	72.60	72.80	73.02
TiO_2	0.77	0.31	0.16	0.29
P_2O_5	0.46	0.30	0.56	0.34
Al_2O_3	15.47	15.02	13.85	14.69
Fe_2O_3	0.85	0.88	0.66	0.64
FeO	2.10	0.83	0.48	0.65
MnO	0.05	0.07	tr	0.06
MgO	0.83	0.14	0.83	tr
CaO	1.93	1.28	1.16	1.40
Na_2O	3.87	3.14	3.96	3.60
K_2O	4.61	5.08	4.24	5.03
H_2O	0.76	0.60	1.07	0.62
	99.93	100.25	99.77	100.34

Analysis no. 81 is a linear augengneiss with euhedral feldspar porphyroblasts from the Saint-Barthélemy massif.
Analysis no. 82 is a muscovite-biotite granitic gneiss from the Trois Seigneurs massif.
Analysis no. 83 is a linear muscovite augengneiss from the Saint-Barthélemy massif.
Analysis no. 84 is a muscovite-biotite-granite from the Trois Seigneurs massif.

TABLE XII

Calc-silicate gneisses

Analysis no.	85	86	87	88	89
SiO_2	65.04	62.30	60.22	58.53	51.86
TiO_2	0.63	1.16	0.60	0.54	1.00
P_2O_5	0.23	0.64	0.26	0.22	0.19
Al_2O_3	15.82	16.32	15.80	16.95	17.96
Fe_2O_3	0.45	1.04	2.44	3.12	2.25
FeO	4.28	3.94	4.20	4.71	5.57
MnO	0.05	0.05	0.10	0.07	0.11
MgO	2.50	2.53	5.37	4.40	2.37
CaO	3.66	5.32	5.93	6.36	17.50
Na_2O	4.29	3.06	1.65	2.36	0.58
K_2O	2.29	2.35	2.60	2.25	0.26
H_2O	0.74	1.07	1.26	0.45	0.46
	99.98	99.78	100.43	99.96	100.11

85. Biotite-quartz-diorite; quartz, andesine, biotite; St. Barthélemy massif.
86. Biotite-quartz-diorite; quartz, andesine, biotite; St. Barthélemy massif.
87. Hornblende-quartz-diorite; quartz, labradorite, hornblende, biotite; St. Barthélemy massif.
88. Hornblende-gneiss; quartz, labradorite, hornblende, biotite; St. Barthélemy massif.
89. Diopside-bytownite-gneiss; bytownite, diopside, hornblende, quartz; St. Barthélemy massif.

Mineralogically various types can be distinguished, dependent upon the kind of gneiss in which they occur, and the metamorphic history. The most common minerals are calcic plagioclase, green hornblende, diopside, cummingtonite, clinozoisite.

Peridotites

Two small outcrops of peridotite have been found in the Saint-Barthélemy massif, one near Etang du Diable and the other due east of the Pic du Han. They are unoriented black rocks in which plates of phlogopite can be discerned with the naked eye. Mineralogically they contain olivine, rhombic pyroxene, tremolite and phlogopite. Similar rocks have been found in the Trois Seigneurs massif, but here they are associated with dolomitic marbles. They have been described by ALLAART (1958).

Chlorite-albite rocks

Rocks consisting almost exclusively of chlorite and albite are widespread in the Trois Seigneurs massif, but they have also been found in the Arize and Saint-Barthélemy massifs. These rocks occur as patches and irregular masses, sometimes rather large, in gneisses, migmatites, biotite-granodiorite and occasionally in the mica-schists. The main characteristic of this rocktype is that in the outcrops no structural changes take place passing from a biotite-quartz-plagiolase rock into the chlorite-albite bodies. This is especially clear in the inhomogeneous migmatites. The mineral content and with it, the microscopical structure of the rock has, however, undergone a complete reconstitution. From the field observations it became clear that these chlorite-albite rocks have replaced the original rock, during which process the biotite was converted into chlorite, the feldspars into albite, whereas quartz disappeared completely or partially. This means that there is a replacement of a high temperature mineral association by a low temperature assemblage. This alteration will have been favoured by the introduction of sodium (see Table XIII). For further details we refer to the thesis of ALLAART (1958).

Quartz dykes and masses

Dykes and rather large outcrops of quartz occur on several places, mainly in the mica-schists and gneisses. Some of the most important ones have been recorded on the map. The largest mass lies in the eastern part of the Arize massif near the Col de Rouy, where this quartz body is quarried. This body is situated in the migmatites. Another large mass occurs in the western part of the Saint-Barthélemy massif in the basal gneiss series. Here the quartz is associated with hematite.

TABLE XIII

Chlorite-albite rocks

Analysis no.	90	91	
SiO_2	54.80	57.15	90. Chlorite-albite rock occurring in biotite-grano-diorite of Pic des Trois Seigneurs
TiO_2	0.77	0.53	
P_2O_5	0.10	0.05	
Al_2O_3	20.50	18.52	91. Epidote-bearing chlorite-albite rock; same locality as 90
Fe_2O_3	0.10	2.26	
FeO	5.57	3.01	
MnO	0.03	0.03	
MgO	2.40	1.82	
CaO	2.58	3.71	
Na_2O	9.08	8.50	
K_2O	1.76	3.00	
H_2O	2.81	1.81	
	100.50	100.39	

CHAPTER 3

METAMORPHIC HISTORY

Although the metamorphic history of the crystalline rocks will be dealt with in a separate publication, a short summary should accompany the description of the rock types.

Many field and microscopical observations taught us, that the metamorphic history of the gneisses and granites is a complicated and long lasting process. In general we can state as a basic assumption that hardly any original sediment escaped deformation during the Hercynian orogeny. In many rocks this deformation is visible, for example in certain gneisses, in the phyllites as well as in the younger Paleozoic sediments by their schistosity, cleavage and lineation. In many other gneisses and most of the granitic rocks, however, such vestiges of tectonic deformation are absent, and also rocks occur which are tectonites on a megascopical scale, but consist of an undeformed mineral aggregate on a microscopical scale. In general the absence of any sign of deformation indicates that such rocks are younger than the orogenic influence, either as a result of reconstitution by recrystallization or as post-tectonic intrusion.

It became clear that the metamorphism started during and probably not before the beginning of the folding, and that this process continued long after the orogenic movements had ceased. Basically we can make a division in synkinematically and post-kinematically recrystallized rocks, but naturally this matter is somewhat more complicated. Any given rock can start its metamorphic life at any moment after the start of tectonization and end it at any other, later moment. This means that, for example, metamorphism can start during the folding and also end before the deformation ceased; this results in a mechanical breaking down of the minerals of the rock, or post-crystalline deformation. It is also possible that crystallization and deformation stop at the same time; this case is represented by paracrystalline deformation or synkinematic crystallization, with can last for a variable length of time. Finally post-kinematic crystallization is possible, but its duration can be short or long. Therefore we can expect a great variety of circumstances, which, as a matter of fact, have been found to prevail during the Hercynian metamorphism. Fortunately the distribution of rocks with the same metamorphic history is not haphazard, but rather regular. In fact, the whole metamorphic sequence is split up in layers, which may be independent of the original sedimentary stratification (see also GUITARD 1955). In such a layer the metamorphic history is similar in lateral direction, or changes very slowly, whereas across such a layer the metamorphic history can change more rapidly. In general the boundaries between the different layers are transitional and have to be chosen more or less arbitrarily. When sharp boundaries occur, they are not the result of a difference in time or duration of metamorphism, but they are due to metasomatic action or to original sedimentary stratification.

On a large scale the metamorphic history of certain rock units can change also in a lateral sense, resulting in wedging out or changing in character of these units. This accounts for the difference of the metamorphic sequence in the three satellite massifs under consideration, which is clearly expressed on the map; see for example extension of the basal gneisses or the migmatites.

Addition of material is another feature which complicates the metamorphic history. For example, a rock can first recrystallize to an isochemical mica-schist and at any moment metasomatism can set in, either syn- or post-kinematically, and the schist is converted into a gneiss or a granitic rock. Metasomatism is one of the most important agents of the Pyrenean metamorphism, if not the most important one. Chemical analyses show that most gneisses and migmatites are enriched in silica and sodium, compared with the original pelitic sediments. Various elements as Al, Fe, Mg are removed during this process.

The mica-schists form the transitional zone between the metasomatic gneisses and granitic rocks on one side and the non-metamorphic sedimentary cover on the other. In the mica-schists the chemical changes during the metamorphism were of minor importance.

Further the temperature has to be mentioned as an important agent in the metamorphism. The mineral associations indicate that all feldspathized rocks were produced under kata- to mesozonal conditions, but a clear record of decrease in temperature is preserved in post-kinematic gneisses and granites, shown by a polymetamorphic mineral assemblage. In rocks which only suffered synkinematic metamorphism such a falling temperature has never been recorded. Properly spoken, areas with synkinematic feldspathization only, seem to have suffered a very sudden decrease in temperature, resulting in a frozen high temperature mineral assemblage; they are mono-metamorphic rocks.

Another important factor is the water content and the behaviour of it in the different rock groups. It appears that synkinematic feldspathization is essentially dry, and only few waterbearing minerals form in these rocks, resulting in mineral associations which very much resemble those of the granulite facies. Post-kinematic feldspathization and granitization, however, takes place under distinctly "wetter" conditions, resulting in a replacement of hydroxyl-free minerals by hydroxyl-bearing minerals. Longlasting post-kinematic granitization seems to result in a thorough "soaking" of the rocks and the intrusive biotite-granites of the Pyrenees are supposed to be the final stage of this process.

Finally the depth of the metamorphism has to be mentioned. Although difference in depth of the Pyrenean metamorphism does not result in different mineral associations dependent upon higher confining pressures, a certain influence of the depth may be present, since the muscovite-granites and gneisses tend to occur rather high in the metamorphic series, often near the top of the migmatites. Microscopical and chemical examination brought to light, that one cause of the formation of these leucocratic rocks is a strong potash metsomatism, which occurred late in the metamorphic history. Since this potash originates from the underlying migmatites, where it has been driven out, it represents a sort of potash-front for which depth probably is rather unimportant.

With all these various metamorphic agents the great variety of rock types in the gneiss massifs can be explained.

In the legend of the map four main divisions of the metamorphic rocks have been made, the first one being the mica-schists, which form the transition between the gneisses and the unmetamorphosed or low grade Paleozoic cover. The three remaining divisions are the basal gneiss series, the migmatite-quartz-diorite series and the muscovite-granite and gneiss series. All three divisions are in themselves not uniform in metamorphic history. This primary division is based on field occurrence and mineralogical and chemical properties. The subdivisions, however, are identical in their metamorphic history.

The basal gneisses

We will start with the basal gneisses, of which the linear and folded garnet-augengneisses are structurally and mineralogically the most simple rocks. They have undergone only synkinematic metamorphism, often with deformation outlasting crystallization. The feldspars and garnets are developed as augen around which the matrix of quartz and biotite is arranged in a flowlike fashion. The feldspars are often porphyroclastic and then the rocks are almost mylonitic. Such structures prevail particularly in the folded augengneisses and the folding is the result of post-crystalline deformation. It should be emphasized that this folding did not take place during a later orogeny, since the lineations of the gneiss and the fold-axes are always strictly parallel.

Towards the bottom as well as towards the top of these augengneisses crystallization gradually lasted longer, which results first in the disappearance of the lineation, and later, as a result of still longer post-kinematic crystallization, in the disappearance of the schistosity. Towards the bottom this is indicated by the schistose gneisses, which are statically recrystallized augengneisses and further downward by granitic gneisses and granites. Relic augengneisses in these granites indicate that all these rocks originally were augengneisses.

The mineral association in the linear augengneisses is quartz, sodic plagioclase, potash feldspar, biotite, garnet and some cordierite. In the schistose and granitic gneisses the same minerals were stable during synkinematic conditions, but during post-kinematic crystallization the temperature decreased and "wetter" conditions prevailed. This resulted in the formation of a little muscovite at the expense of biotite or feldspar, and the conversion of garnet and cordierite into biotite and phlogopite. A similar retrograde metamorphism took place in amphibolites and lime-silicate rocks. The synkinematic paragenesis of the amphibolites is bytownite, green amphibole and biotite and of the calc-silicates: bytownite, forsterite, hypersthene, diopside, calcite. During the post-kinematic phase the following retrograde minerals were produced: calcic scapolite, epidote-clinozoisite, green hornblende, cummingtonite, tremolite, clinochlore and serpentine.

Towards the top a similar kind of evolution takes place, with this difference that the beginning of the feldspathization starts later, in such a way that in the overlying migmatites the main phase of feldspathization is postkinematic. Relics of augengneisses are absent in these migmatites. The transitional layer between the garnet augengneisses and the migmatites are the granitic biotite-muscovite-gneisses. In their lower part they are clearly related to the augengneisses, but show a certain post-kinematic recrystallization during which muscovite was formed. Near the migmatites the typical augen-character and the lineation disappear to make way for the typical texture of the migmatites, in which post-kinematic recrystallization has almost obliterated all signs of deformation. In the migmatites the beginning of the feldspathization took place during a late phase of the folding, because several observations indicate, that movements still influenced the quartzo-feldspathic bands of the sillimanite-gneisses. These movements were, however, of different nature than in the augengneisses; no augentexture, neither lineations were produced. In this way the muscovite-biotite granitic gneisses are a rock series, in which the onset of feldspathization took place later as one approaches the migmatites. At the same time the end of the feldspathization also occurred later.

In this way the garnet-augengneisses are below and above bordered by rocks which are influenced by post-kinematic recrystallization. It is interesting to note, that in the eastern part of the Saint-Barthélemy massif this augengneiss zone is very thick, but that to the west this zone gradually becomes thinner. This wedging out is the result of the two static recrystallization fronts approaching one another; further to the west these fronts even joined and in the Trois Seigneurs massif the garnet-augengneisses are present only as statically recrystallized relics (the homogeneous biotite-gneisses near Lapège).

The migmatite—quartz-diorite series

We concluded already that late- to post-kinematic feldspathization of the mica-schists led to the formation of migmatites. The quartz-diorites at their turn formed at the expense of the sillimanite-gneisses by continuing post-kinematic recrystallization, favoured by introduction of silica and sodium.

The repartition of sillimanite-gneisses and quartz-diorites in the three satellite massifs leads to the same conclusion as we already have drawn for the basal gneisses, that is post-kinematic crystallization becomes more and more predominant in western direction.

In the Saint-Barthélemy massif quartz-diorites occur only in the midst of sillimanite-gneisses, although they are somewhat more abundant near the base. In the eastern part of the Arize massif quartz-diorites occur as a zone below a several thousand metres thick layer of sillimanite-gneisses, but towards the west the thickness of the migmatites decreases and in the central part of the Arize massif only a few hundred metres of sillimanite-gneisses are exposed at the cost of the underlying quartz-diorites. The Trois Seigneurs massif shows a similar arrangement as in the central part of the Arize massif. Here also only a few hundred metres of sillimanite-gneisses occur above many thousands metres of quartz-diorites. In this latter area continued recrystallization leads to a new process: mobilization or rheomorphism (ALLAART, 1958). This process is probably due to soaking with fluids, and results in flow movements and disorientation of inclusions, without coming to an intrusive stage (see fig. 11 and 12). Therefore, these quartz-diorites are still autochthonous. In the Saint-Barthélemy and Arize massifs rheomorphism also took place, but on a smaller scale. Of course this mobilization adds greatly to the homogenization of the quartz-diorites. Although further stages of mobilization have not been observed, neither on this map-sheet nor elsewhere in the Pyrenees, the conclusion seems warranted that continued mobilization may lead to intrusion and that in this way the biotite-granodiorites were produced. The great chemical similarity between the metasomatic quartz-diorites and the intrusive granodiorites certainly favours this supposition.

The muscovite-granite and gneiss series

The various rocktypes of this series have a number of features in common; these are sharp contacts with enclosing rocks, mineral assemblage with quartz, sodic plagioclase, microcline, muscovite and biotite, similar chemical composition and a late phase of microclinization. There are different structural types, augengneisses, schistose gneisses and massive granites.

The augengneisses occur as a big sheet in the Saint-Barthélemy massif and the eastern part of the Arize massif. Microscopical examination showed that the augentexture is a relic and that these gneisses are recrystallized under static conditions, without much alteration of the megascopical properties. This is due to the fact that the replacing minerals have a very fine grain, which gave rise to pseudocataclastic textures (= mesostase II of GUITARD, 1955). It appeared that this replacement was favoured by the introduction of potash since plagioclase augen are replaced by microcline and muscovite. Locally, mainly in the eastern part of the Saint-Barthélemy massif large, euhedral microcline porphyroblasts grew in these gneisses, but these porphyroblasts are comparable to the small late microcline crystals; there is only a difference in size and crystal habit. The augengneisses of the Aston massif south of sheet 3 belong to the same unit and suffered the same late microclinization.

The muscovite-biotite granitic gneiss of the Trois Seigneurs massif has almost the same metamorphic history, but the early phase of formation of augengneisses seems to have taken place somewhat later, probably towards the end of the folding. The late muscovitization and microclinization occur in exactly the same manner as in the augengneisses. The muscovite- and muscovite-biotite granites, which occur at many places in the Arize and Trois Seigneurs massifs, again show a similar late muscovite- and microcline formation at the expense of biotite and plagioclase as the described gneisses, but it has to be assumed that the rock before the late microcline formation was already a post-kinematic, unoriented granite or granodiorite.

The most remarkable feature of the muscovite-granite and gneiss series in this late microclinization of an older plagioclase-rich rock. This process must have been the result of introduction of potash, probably driven out of the underlying migmatites. Since it is most probable that the age of the microclinization is the same for all the different rock types, it can be concluded that the original plagioclase-rich rock was of synkinematic age in the eastern part, and of post-kinematic age in the western part of sheet 3, because in the first case a linear augengneiss and in the last case an unoriented rock was attacked by the microclinization process. This leaves at least for the augengneisses a considerable gap in time between the synkinematic formation of augentexture and the post-kinematic microclinization.

The sharp contacts of these rocks will be the result of differential metasomatism, transforming part of the mica-schists into augengneisses or granodiorites. During the microclinization these rocks apparently were very susceptible to this process, but the migmatites underwent the same late muscovitization and microclinization.

In the foregoing we advanced the theory that the Hercynian metamorphism can be split in two main phases, a synkinematic and a post-kinematic one. It is logical to assume that a similar development can be expected in the mica-schists. In fact this has been observed, and in many mica-schists a strong static recrystallization has taken place. The synkinematic paragenesis is biotite I, muscovite I, andalusite I, (staurolite), the first postkinematic paragenesis is biotite II (cross-cutting) and andalusite II. Locally, mainly in the Trois Seigneurs massif, fibrolite formed after this first post-kinematic stage and finally cross-cutting muscovite II formed. This development is very similar to the one in the sillimanite-gneisses and quartz-diorites.

Summarizing we can state that there are two rock groups which show a complete scale of syn- and post-kinematic feldspathization, on the one hand the basal gneisses and the migmatites and on the other the muscovite-granite and gneiss series. The latter series, however, is influenced by an important potash metasomatism resulting in a late phase of microclinization and muscovitization, which, in part, is responsable for the leucocratic composition of these rocks. Since the necessary potash probably originates from the migmatites, the general position of these muscovite-granites and gneisses high in the metamorphic sequence, seems to be controlled by the underlying migmatites.

Comparison of chemical analyses of the original pelites with the feldspathized rocks, indicate an introduction of Si, Na and little Ca in all these feldspathic rocks. At the same time K was expelled from the migmatites and entered the muscovite-granites and gneisses. Most feldspathized rocks show a decrease in Al, Mg and Fe, but this is especially clear in the muscovite-granite and gneiss series.

As to the destination of these elements, some remarks have to be made.

Firstly there is no basic front to account for the Mg and Fe. It is, however, not impossible that the magnesium which has been driven out, was responsible for the dolomitization of the Upper Paleozoic limestones. This dolomitization is clearly post-tectonic and pre-Mesozoic, which means that the age of the dolomitization could be correlated with a late phase of the metamorphism. The iron could be deposited in the Upper Paleozoic as iron ore, as pointed out by AUTRAN and GUITARD (1957). The aluminum did not move much and was precipitated as metasomatic fibrolite in some of the mica-schists (ZWART, 1958) and possibly also in the migmatites. In the talc deposits of Trimouns aluminum has been introduced also, resulting in the occurrence of much clinochlore in the talc.

CHAPTER 4

STRUCTURE

(see structural map fig. 1, and sections Plate 2)

Introduction

The Pyrenees Mountain chain is divided in a series of longitudinal zones of which, from a structural point of view, the outer and youngest ones on both sides are the marginal troughs, and the central axial zone is the oldest. The axial zone consists almost exclusively of Paleozoic rocks, the marginal zone is filled with Tertiary strata. Both on the north and south flanks of the axial zone a particular internal zone intervenes between the axial zone and the marginal troughs which in the case of the northern internal zone is characterized by a thick development of the Lower Cretaceous, surrounding cores of more or less isolated Paleozoic masses, the satellite massifs. On our map occur large parts of two of such satellite massifs, the Arize and Trois Seigneurs massifs, and the whole of the Barthélemy massif. The axial zone is represented by a triangle in the SW corner of the map and a strip of paleozoic rocks along its southern limit. In the northern part of the map occurs a strongly compressed mesozoic boundary zone as a narrow strip between the internal zone and the marginal trough.

The faults

The Trois Seigneurs and Barthélemy massifs are separated from the axial region by zones of strongly compressed mesozoic rocks, often of a metamorphic character and intruded by small ultra-basic or basic rock units. Between the Arize and Barthélemy massifs in the north and the Trois Seigneurs massif and axial zone in the south a lozenge-shaped basin the Tarascon basin also filled with Mesozoic rocks has been formed. This lozenge penetrates as a wedge between the Arize and Trois Seigneurs massifs until a little beyond the Col de Port, further westwards the two massifs are joined and only separated by a fault zone.

The Cenomanian has been proved by CASTERAS (1933), to be deposited unconformably on the Lower Cretaceous and the metamorphism of the Lower Cretaceous does not affect the Cenomanian, neither do the basic rock intrusion ever penetrate into the Cenomanian. Therefore the breaking up of the Paleozoic substratum in blocks forming the satellite massifs, must have occurred partly at least in a late Cretaceous Laramide phase of the Alpine orogenesis of the Pyrenees. Actually it can be shown that the origin of the fault zones, separating these blocks from one another and from the axial zone, must lie even further back in history, it probably has a late Hercynian pre-Triassic age, but it remains very difficult to assign to each of the possible phases of movement its proper share (DE SITTER, 1954b).

A look on the map shows us that the Arize and Barthélemy massifs form almost a single unit in which the metamorphic and stratigraphic zones run from west to east curving round slightly towards the south. In this whole curve the originally deepest rocks crop out on the southern and the youngest on the northern boundary. When we step over its southern limiting fault zone, we arrive again on younger and higher rocks. Therefore an important function of this fault zone has been a vertical movement with a downthrown southern and upthrown northern block. The latter has been tilted, an originally horizontal plane is now dipping towards the north. The same kind of movement can be discerned in the Trois Seigneurs massif, but the tilt seems to be less pronounced and is perhaps more to the west than to the north. That this faulting and tilting occurred before the start of the mesozoic sedimentation is proved by the fact that along the north and east margin of the Barthélemy massif there is a gradual overlap of Triassic, Jurassic and Cretaceous on Paleozoic from north to south with the result that the Cretaceous reaches furthest to the south and the Triassic is only found on the northern margin. The Triassic occurs also in a special gypsiferous facies near Arnave and Arignac in the triangle between the three massifs.

In the compressed zone between the Barthélemy—Trois Seigneurs massifs and the axial zone Triassic and possibly Jurassic is again present, therefore the tilted blocks probably once were islands in the Lower Mesocoic shelf sea.

The distribution on the map of the outcropping formations is of course not only dependent on the tilting which occurred after the Hercynian folding, but also on this fold pattern itself, as for instance the alternative bands of Devonian and carboniferous rocks on the northern slope of the Arize-Barthélemy massifs representing Hercynian anticlines and synclines. The three massifs together certainly show a structural culmination with its centre just south of the Barthélemy dome, and one would be tempted to regard this culmination as an individual and original dome. The sequence of metamorphic zones in the three satellite massifs and in the Aston massif of the axial zone just south of it, is so similar that they must be regarded also as belonging to one original unit, one dome of rising metamorphism. Therefore the strongly compressed band of non metamorphic Upper Paleozoic along the northern border of the axial zone, exposed in the Ariège valley between Bonan and Luzenac, is probably a later structural feature, a synclinal folding splitting the original dome in two parts. This syncline runs from east to west partly along the present position of the north-Pyrenean fault, interrupted only by the late Hercynian intrusion of the Auzat granite mass.

The suggested sequence of events is as follows: first synkinematic feldspathization forming an enormous dome. Then a splitting up of the large dome in two halves by a synclinal fold running from east to west. This phase is followed by the late tectonic intrusion of the Auzat and Foix granites and finally by a faulting phase separating the axial zone from its foreland and splitting up the foreland in blocks which were tilted. This process must not be seen as a sequence of phases separated by periods of quiescence but as a continuous process. It is quite probable that the Laramide folding shifted the blocks again and compressed not only the faultzones, but also the marginal zones of the satellite massifs and of the axial zone, and even increased the original tilt. The synkinematic metamorphism was certainly accompanied by folding in the higher levels of the crest, but the deep furrow along the line′ which later became the north-Pyrenean faultzone seems to be a relative late phenomenon in the folding process.

The intrusion of the Auzat, Trois Seigneurs and Foix granites has deformed the structural pattern to some extent. In particular round the western side of the Foix granite the formation limits suggest a doming caused by a vertical push of the rising granite, and around the Trois Seigneurs stock the schistosity is parallel to the boundary.

The granite mass of Auzat is accompanied on its northern limit by a narrow zone of Cambro-Ordovician schists and limestones folded in a almost vertical isoclinal anticline. The north flank of this anticline is very steep and reaches deeply downwards and can be followed far towards the west and as such forms the southern flank of the above mentioned furrow between the satellite massifs and the axial zone.

The intrusion of the Auzat massif is clearly linked to this steep flank and therefore to the synclinal furrow mentioned above, but somewhat later because it interrupts the syncline also.

The relation between the Barthélemy and Arize massifs needs a closer examination. Originally both DE SITTER (1954) and ZWART (1954) thought that a considerable horizontal shift of the Barthélemy massif towards the south along a wrench fault running first roughly along the Arize valley from Foix southwards and then over Antras could explain the almost 10 km shift of the northern boundary.

A more detailed mapping of the slopes of the Arize valley downstreams of Tarascon revealed that no fault of any importance can be supposed to run in that part of the valley. The fault running from Antras to Croquier moreover dies out very quickly southwards and shows hardly any throw in the lower gneisses south of Croquier. It seems more probable that the original horizontal shift runs along the fault which branches off halfway between Croquier and Antras and runs towards the SE between the granite gneiss in the south and the sequence of metamorphic Cambro-Ordovician on its north side. The continuation of this fault cannot be traced where it runs parallel to the schistosity in the granite gneiss, but it might be possible that it joins up with the important fault just south of the Pic du Barthélemy.

The movement between the two massifs can be surmised to be in the first place a wrench fault movement with a SE strike and later a hinge movement, partly along the already existing fault plane, partly along new NS running faults due to the greater tilting of the Barthélemy mass.

A conjugate wrench fault can be perhaps recognized in the SSW—NNE running fault south of Ganac, starting in the Foix granite and cutting into the schistzone south of it.

The big fault between the Arize and Trois Seigneurs massifs is soon lost below the Cretaceous cover of the Tarascon basin. It finds its continuation without doubt between the Barthélemy massif and the axial zone. Within the Trois Seigneurs massif we find a parallel fault, running over the Col d'Estagnou with the same sense of movement, a downthrow of the southern limb. The movement is repeated again on the branch of the north-Pyrenean fault between the Trois Seigneurs massif and the axial zone. But there is some reason to suspect that along this branch of the fault a considerable horizontal shift has occurred, the Trois Seigneurs massif having been moved westwards, because then the Trois Seigneurs granite massif and the Auzat granite mass could represent homologous elements (ZWART 1954). On the other hand both small granite outcrops of Sentenac and Les Bordes north of the main fault zone lie in the direct continuation of the Auzat granite, and the Trois Seigneurs granite mass could as well be a small independent stock.

In a previous note DE SITTER (1954) has demonstrated that the complex fault pattern which forms the north-Pyrenean fault zone is due to the interference of two fault directions of different age. The older late-Hercynian phase had a E—W strike, the younger Laramide phase a N 100° E direction. The wrench fault between the Barthélemy and Arize massif belongs to the older phase, and some of the tilting of satellite massifs also, but extra tilt in the same sense happened after the Laramide phase as is proved by the thick accumulation of younger Cretaceous sediments in the Nalzen basin north of the Barthélemy massif.

The folds

(See sections 1, 2 and 3, Plate 2)

In the metamorphic part of the Cambro-Ordovicien it is almost impossible to distinguish a fold structure in the metamorphic zones, and even in the non-metamorphic portions of this thick formation structures are only revealed when distinctive rock types occur. Thus the broad band of Cambro-Ordovician on the southern side of the Arize massif shows only one distinctive syncline of Silurian, but many more structures are probably present in this zone, which cannot be mapped. In the Trois Seigneurs massif the streaks of metamorphic marbles together with some streaks of pegmatite or more gneissic rocks in micaschists indicate perhaps two synclines.

The Barthélemy massif constitutes one large dome of Upper-Paleozoic rocks round a core of highly metamorphic Cambro-Ordovician.

It is only in the Upper-Paleozoic sequence of Silurian, Devonian and Carboniferous of the north sides of the different massifs and of the axial zone, that structural details of the folding are revealed.

Of the Arize massif KEIZER, (1954) gives a set of sections which show that the axial planes of the folds dip towards the south (see section 1), and that the whole zone occupied by the Upper-Paleozoic contains two major synclines separated by a central anticline, which disappears eastwards. From a general point of view this structure gives the impression of an interference of a E—W direction with a N 70° E direction. The E—W strike we have already recognized as that of the deep furrow between the axial zone and the satellite massifs. The N 70° E strike seems to be connected with the doming effect of the Foix granite which we have already recognized as a somewhat later phenomenon.

The main anticlinal and synclinal structures show many secondary folds with the same position of the axial plane.

In the Arize massif we have one of the very rare instances where we can trace the influence of Alpine folding on the Upper-Paleozoic cover. A few synclinal streaks of Triassic are preserved lying on the Paleozoic. The one near the western limit of the map, just south of Feillet is clearly discordant on Carboniferous and Devonian, the one just downstreams of La Barth on the Arize river lies on Carboniferous strata. Their flat positions show that here very little folding has been added to the Hercynian folds by the alpine folding.

The folding of the Upper-Paleozoic round the Barthélemy massif is of a more complicated nature (see section 3). The round core of more or less metamorphic Cambro-Ordovician is surrounded by an almost unfolded cover of Silurian and Lower plus Middle Devonian dipping quietly away from the core. This central part is surrounded by a zone consisting of Upper-Devonian and Carboniferous, strongly folded and separated from it by a continuous fault zone. There can be no doubt that in this case this upper sequence has been detached from the start of the folding process by a basal shearing plane from its basement. Because this plane of detachment in its present position brings Carboniferous strata in contact with the Lower or Middle Devonian, the movement along it must have been considerable. The Upper Devonian-Carboniferous sequence is even everywhere reversed (see section 3) the Devonian lying in isoclinal synclines on the Carboniferous.

On the south side of the massif we find one curious outcrop of Upper-Devonian near Lordat lying discordantly on the folds of the Lower-Devonian.

On the northern side of the massif the Cretaceous cover, both the pre- and post-Laramide sequences, have a vertical position, whereas on the east flank they are flat. Because the Devonian-Carboniferous isoclinal folds show exactly the same change from vertical to flat positions, there can be little doubt that the Pyrenean folding has changed their original flat Hercynian position to the vertical.

The original suggestion of ZWART (1954), that this curious structure is due to gravity gliding of the upper formations down the slopes of the dome, certainly is the most probable explanation. This must have happened after the deep furrow between the Barthélemy massif and the axial zone had been formed, and no doubt was due to the doming effect this had on the Barthélemy massif. The original detachment of the upper layer had possibly its origin in the folding which preceded the splitting up of the Aston-Barthélemy dome.

The structure of the Paleozoic cover of the axial zone has been described by ALLAART (1954). The folds are isoclinal and vertical and consist of a central Silurian anticline, running from Larnat to Luzenac, and synclines on both sides (see section 3).

Approaching the blunt point of the Arize massif the whole structure curves from E—W to the south, is then cut of by an E—W branch of the North Pyrenean fault near Auzat. The Cretaceous, covering this structure unconformably from Lordat west and southwards, has also a vertical position. Therefore this curve of the anticlinal structure has an Alpine age and it certainly has been further compressed by this younger compression.

The continuation of this zone can be found near Aulus. Here an anticlinal fold in the Cambro-Ordovician is revealed by the massive limestone, and the broad band of undivided Devonian consists certainly of a whole sequence of vertical folds.

CHAPTER 5

ECONOMIC GEOLOGY

Except the talc exploitation in the St. Barthélemy massif and a gypsum quarry the region represented on our map does not contain any present exploitations of importance.

In the 19th century several ore deposits have been worked of which the iron ore of Rancié in the south and the lead-zinc ore of Montcoustant in the Arize massif are the principal ones. The Rancié iron ore occurs in the Devonian limestones bordering the axial zone near the village of Lercoul and part of the ancient mine works actually fall within our map region. We will not give a description of this occurrence here because sheet 6 will give us a better opportunity to discuss its geological setting.

The principal source of knowledge of all the ancient ore occurrences is the work of MUSSY dating from 1868—69 to which we refer the reader for more details. As we never made a survey of the building and ornamental stone industry we will leave this subject alone.

Combustible mineral resources are unknown in our region except very local peats in the mountain valleys, but they never served for anything else but occasional local supply.

Iron

From numerous localities iron ores have been reported, often consisting of oxydized siderite, more often sulphides. The typical reduction facies of the Silurian gives rise to frequent occurrences of pyrite and marcasite, which often has lead to small excavations. The rather high iron content of these shales, nearly always giving rise to ferruginous sources, can easily be mobilized and then be concentrated either on particular horizons in the shales or metasomatically in adjoining limestones. None of them ever lead to any exploitation of importance in modern time, but many show evidence of older working. Such iron occurrences are reported from the western part of the Arize massif near Riverenert, where the iron has been concentrated between the Devonian shales and limestone and from Mont Coustant in the eastern part of this massif. There mispickel is the main constituent and has given rise to a production of arsenicum. Similar occurrences are reported from the zone between the St. Barthélemy massif and the axial zone. In this latter zone iron has been worked in the mines of Chateauverdun, further near Larcat on the Aston river. The old works in the Devonian limestone near Alzen in the Arize massif have another origin. The deposition of the hematite-limonite ore in an enlarged joint system of karst appearance indicates that the iron has been derived by leaching from the red Triassic. In the Triassic itself we find concentrations of hematite certainly due to concentration of iron from the often very ferruginous red beds. On the northern border of the Arize massif they have given rise to small exploitations near Les Andreaux between Barquac and Montels.

The large iron accumulations of Rancié and Lercoul, principally in Devonian limestone will not be described here.

A curious iron deposit occurs next to the ophitic rocks in the anticlinal structure of the Lower Mesozoic south of Rabat. The ore consists at the surface of limonite with a thickness of four to five metres and a length of 50 metres (not marked on the map). At depth the ore containing there pyrite and magnetite next to the oxydized ore, appears to be interstratified with ophite. Apparently the iron is of purely magmatic origin.

Manganese

In the Triassic, and associated with the iron, manganese has been worked near Montels in the Arize massif. It certainly is of syngenetic origin as so many other red bed manganese concentrations near a major unconformity. On the red sandstones of the Triassic overlying the Devonian on the northern border of the Arize massif, follows first the iron ore bed of about 1 metre thickness, then another red sandstone bed followed by lenses of maximum 50 cm thickness of pyrolusite. This iron-manganese sequence is covered by a conglomerate which contains rounded pebbles of manganese. These pebbles have a core of calcite, and it seems possible that they represent simply limestone pebbles partly metasomatically replaced by manganese. The occurrence of manganese ore in the Upper Devonian near Las Cabesses, just outside our map has also been referred to as of syngenetic origin related to the emergence during the Tournaisian. The manganese occurs in the Devonian griottes together with zones of manganiferous black earth and extend from the principal mine of Las Cabesses along the contact of Carboniferous cherts and the Upper Devonian for about 20 km length eastwards (LOUGNON, 1956).

The ore occurs in cavities in the limestone and consists of an upper oxydized zone of some 20 metres depth and a primary zone below that depth of dialogite and hausmannite. There are good reasons to believe that this ore is also syngenetic, not only because it is bound to this particular stratigraphic horizon from the Arize massif to the eastern Pyrenees and the Montagne Noire, but also because manganiferous shales occur somewhat higher in the Carboniferous (Visean). Their manganese content is certainly derived from the underlying manganese ore and as the magmatic intrusions are of a later date (late-Carboniferous) the manganese cannot have a magmatic origin (THIÉBAUT, 1935).

Lead and zinc

Among the numerous lead and zinc ore occurrences mostly in quartz or barite veins in the Paleozoic of our map sheet only one ever reached a reasonable exploitation stadium, all the others represent small pockets which were abandoned after they had been emptied. The exception is the Mont Coustant mine in the eastern Arize massif which, however, was shut down about 80 years ago. The exploitative period fell between 1862 and 1878. The mine is situated in the Upper Ordovician schists not far away from the Foix granite contact, but outside its thermal contact aureole. The ore occurs in a dolomite, which may either represent a lens of Ordovician dolomite of the same age as the limestone (dolomite) of Trimouns or a Silurian dolomite. Immediately in contact with this carbonate sediment occurs a dyke of basic character which is not mineralized. The ore consists of lead and zinc sulphide, often in separate zones, the zinc being nearer to the contact with the surrounding schists. The sphalerite is later than the galenite. The exploitation was completely restricted to the galenite, and the sphalerite was either left standing in the mine or can be found in the tailings. In 1950 the owner sold these sphalerite tailings to a local man who proceeded with washing them for their zinc ore content.

Galenite occurred in massive lenses in two parallel zones in the limestone separated by some 30 m sterile rock. The largest zone of lenses is the northern one, at 60 metres depth it has a length of 50 to 60 metres. The southern zone measured at 50 metres depth 0,50 by 60 by 15 metres.

Talc deposits

In the eastern part of the Saint-Barthélemy massif two important talc deposits occur at the base of the Cambro-Ordovician dolomite marble. The deposits are worked in the Trimouns quarry, by far the largest of the two and one of the largest single talc producers of the world, and in the Porteille quarry. In the Trimouns quarry a continuous zone of at least two km length of talcbearing rocks underlies the dolomite. Locally this zone reaches a thickness of 40—50 metres. In the Porteille quarry the thickness of the talc does not exceed 5 m. The extension of this zone is much smaller than near Trimouns. Outside these two talc belts a few talc-schists were found elsewhere in the same massif below the Cambro-Ordovicien dolomite. Both deposits have been elaborately described (ZWART, 1954).

The talc-schists occur in an area where the metamorphic front has risen particularly high in the sedimentary sequence, and immediately below the talc mesozonal mica-schists are exposed, which a few hundred metres deeper are replaced by migmatites and leucocratic gneisses. Above the dolomite the metamorphic grade seems to be distinctly lower, but the graphitic shales of the Silurian usually do not show much signs of metamorphism. Near Porteille chiastolite was found in these schists indicating that they are evidently metamorphosed. The Devonian limestones above the Silurian also are recrystallized. Yet, we have to assume that the Cambro-Ordovician dolomite acted as a screen, above which no metasomatism and only little metamorphism could influence the rocks.

The talc-schists are usually strongly sheared rocks in which many slickensides occur. Only locally undisturbed portions have been found in which the original structure of the talc-schists is still present. These rocks consist of pure white steatite, in which sometimes a distinct banding, caused by graphite, is observable, which is exactly similar to the banding in the overlying dolomite. Also the transition dolomite, over dolomite-talc rock to pure steatite indicates that the talc is a metasomatically altered dolomite. The talc-schists are white, gray or greenish rocks. The colour depends on impurities in the talc-schists. Most of these impurities consist of pure Al-Mg-clinochlore. The more clinochlore, the greener the talc schists are. The total amount of clinochlore can reach up to 80 or more percent and in fact most rocks are talc-chlorite-schists. Other impurities are graphite and ore, which tend to change the colour to gray. These impurities are present only in a few percent.

Several tourmaline bearing pegmatites have been found in the talc-chlorite-schists. They do not penetrate the overlying dolomite. The borders of these pegmatites show a rim of several cm thickness consisting of clino-

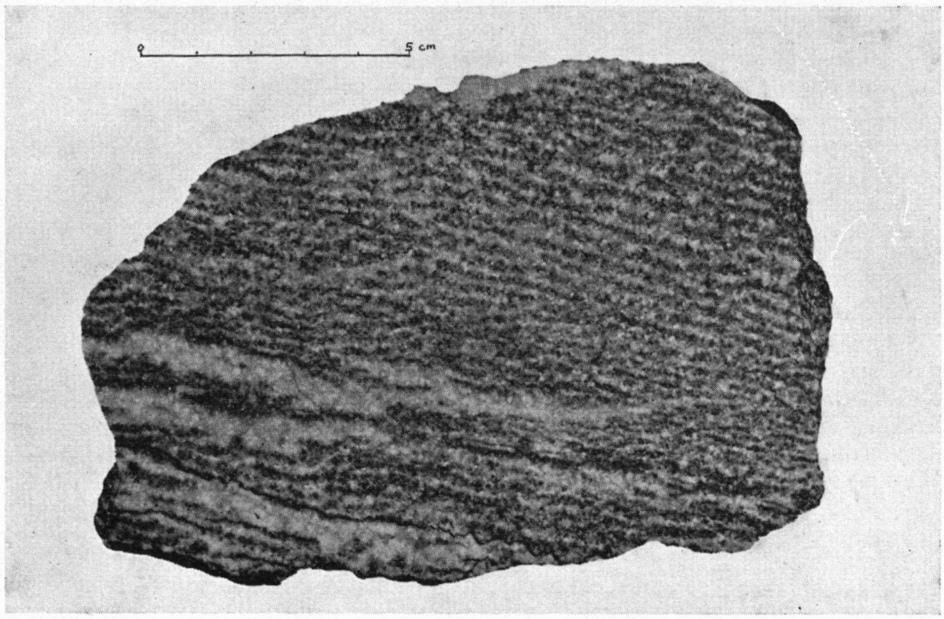

Fig. 15. Ordovician dolomite with banding due to graphite layers; Trimouns quarry; Saint-Barthélemy massif (after ZWART, 1954).

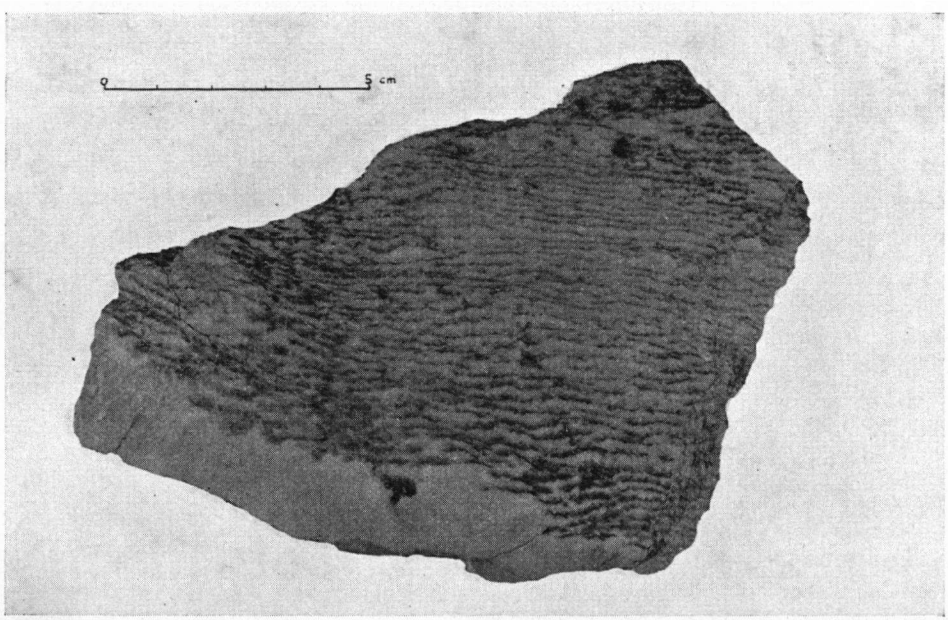

Fig. 16. Steatite which has replaced the dolomite; Trimouns quarry, Saint-Barthélemy massif (after ZWART, 1954).

Fig. 17. View of the Trimouns quarry towards the east (after Zwart, 1954).

chlore with a rather large amount of apatite. A few peculiar dykes of muscovite-apatite rock have been found.

Field- and microscopic examinations made it clear that the talc-chlorite rocks are metasomatically altered dolomites. During this process silica was introduced, which reacted with dolomite:

$$\underset{\text{dolomite}}{3\,CaMg(CO_3)_2} + 4\,SiO_2 + H_2O \rightarrow \underset{\text{talc}}{Mg_3Si_4O_{10}(OH)_2} + \underset{\text{calcite}}{3\,CaCO_3} + 3\,CO_2$$

There is little doubt that the introduced silica is related to the regional feldspathization below the talc-schists. During this feldspathization also silica was introduced. It is noticeable that even above the migmatite front a strong silica introduction took place, whereas the only metasomatic influence in the mica-schists consists of a great number of pegmatite dykes. The fact that in the dolomite itself no pegmatites are present indicates, that no metasomatism was active there.

It is an attractive idea to suppose that the origin of the magnesium in the dolomite and in the talc must be sought in the loss of this element by the migmatites below. Since loss of water played also an important role in the migmatization process one could call the dolomitization and the talc metasomatism, being principally an introduction of silica, magnesium and water, a hydrothermal process if this term were not generally used as a specific late magmatic process.

Besides the formation of talc, another reaction will have been important:

$$\underset{\text{dolomite}}{9\,CaMg(CO_3)_2} + 6\,SiO_2 + 2\,Al_2O_3 + 7\,H_2O \rightarrow$$

$$\underset{\text{clinochlore}}{6\,SiO_2 \,.\, 2\,Al_2O_3 \,.\, 9\,MgO \,.\, 7\,H_2O} + \underset{\text{calcite}}{9\,CaCO_3} + 9\,CO_2$$

The presence of much clinochlore in the talc-chlorite schists indicates that also aluminum was introduced. This is confirmed by the chemical composition of the talc-chlorite schists, which sometimes contain up to 15 % Al_2O_3, besides approximately 45 % SiO_2, 30 % MgO and 10 % H_2O. No original sediment can account for these values. Probably the introduced aluminum originates from the underlying pelites, and was expelled from these rocks during the granitization.

Another element which probably is of metasomatic origin is phosphor. In and along the pegmatites in the talc-chlorite schists a rather great quantity of apatite is sometimes present. Since these pegmatites are most probably of metasomatic origin, it will be clear that also the phosphor is transported in this way. Although in the underlying migmatites an addition of sodium took place, no enrichment in alkali has taken place in the talc-chlorite schists.

Besides introduction of silica and aluminum, other substances namely calcite and CO_2 disappeared. The calcite is partly precipitated as large crystals in the overlying dolomite.

Tremolite occurs near Pitourless, south of Trimouns, and is connected with quartzdykes in the dolomite. Locally this tremolite can be replaced by talc. In the Porteille quarry many octaeders of pyrite are of frequent occurrence in the talc-chlorite-schists. For the rest the mineralogical composition and the structural relationships of the talc deposits of Trimouns and Porteille are similar.

As has already been mentioned much of the talc-chlorite-schists are strongly sheared by later movements and the very large deposit of Trimouns is probable a tectonic accumulation.

Gypsum

Near Arnave and Arignac in the Arize massif gypsum and anhydrite occur in economic deposits. The Arignac deposit is still quarried, whereas the Arnave gypsum has been abandoned. The gypsum lies unconformably on, or in faultcontact with the gneisses of the Arize massif and is covered by Albian shales, probably in abnormal contact. The gypsum is associated with cavernous limestone and metamorphic marbles, which carry several different minerals.

Undoubtedly the gypsum is an evaporite facies, deposited during the Triassic in the Tarascon basin, when this was a still closed basin limited by recent faults.

The gypsum, anhydrite and associated limestones were metamorphosed at the same time as the whole pre-Cenomanian belt along the axial zone. The same characteristic mineral association has been described by LACROIX (1894) viz. scapolite, albite, actinolite, clinochlore, pyrite, tourmaline, biotite, phlogopite and epidote. This association is low to medium grade. Close to the Arnave gypsum a small ophite crops out in Mesozoic limestones.

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