GEOLOGICAL MAP OF THE PALEOZOIC OF THE CENTRAL PYRENEES

SHEETS 1 GARONNE, 2 SALAT, FRANCE
1 : 50.000

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Explanatory text

by

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(with two coloured geological maps 1 : 50.000, Plates I and II and sections Plate III)

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CONTENTS

SUMMARY

The geology of the map sheets 1: 50.000, 1 Garonne and 2 Salat of the Geological map of the Central Pyrenees is described. The stratigraphic sequence consists of Paleozoic rocks from the Cambro-Ordovician to the Carboniferous, and of Mesozoic rocks from the Trias up to the Tertiary. Hercynian and Alpine orogenies have acted on this intercontinental mountain chain. The Hercynian orogeny is accompanied by epi-to cata-zonal metamorphism in which several successive stages can be recognized. The Alpine orogenesis consists also of successive stages of which the Pre-Cenomanian one has been accompanied by basic rock intrusion and a particular kind of metamorphism. In the structure presented on these sheets a stretch of the axial zone is represented and a part of the external zone containing six of the satellite massifs, the two units separated from one another by the north Pyrenean fault zone.

INTRODUCTION

After publishing the map sheets 3, 4 and 5 of the Geological map of the Paleozoic of the Central Pyrenees in 1959 and 1960 [1]), the sheets 1 and 2 get their turn in this paper.

The mapping was done in the summers of 1948—1955 by some 14 students of the Geological department of the Leiden University, controlled and helped by the present authors. Their names and territories are mentioned on the map sheets. Revision of the metamorphic rocks and some details were carried out by the second author in 1959 and 1960.

We realize that the digestion of all the field and laboratory data of the sheets 1 and 2 is perhaps less thorough than that of the sheets 3, 4 and 5 as no doctor thesis work has been concerned with it, but because no work has been planned in this region for the future we think that the publication of the maps accompanied by a short description is necessary now. The maps were printed in late 1960 already, and some corrections are not included. One is mentioned on p. 220, another one is the little map by Souquet (1960) on the eastern end of the Castillon massif.

The topographic base of the maps has been derived from the 1: 20.000 French maps, although they were not available yet during the mapping, which was done mostly on aerial photographs and on the 1: 50.000 Spanish map.

We extend our sincere thanks to the printer of the maps Mouton & Co, the Hague and our draughtswoman Miss C. Roest for their efforts to produce the maps.

[1]) de Sitter, L. U. & H. J. Zwart, 1959. Geological map of the Central Pyrenees, Sheet 3 Ariège. Leidse Geol. Med. 22, 351—418.

Kleinsmiede, W. F. J., 1960. Geology of the Valle de Arán. Geological map of the Central Pyrenees, Sheet 4, Valle de Arán. Leidse Geol. Med. 25, 131—244.

Zandvliet, J., 1960. The Geology of the Upper Salat and Pallaresa valleys. Geological map of the Central Pyrenees, Sheet 5, Pallaresa, Leidse Geol. Med. 25, 1—127.

STRATIGRAPHY AND PETROGRAPHY

The development of stratigraphical sequence concerned in the building up of the Pyrenean Mountain chain consists principally of two units, the Paleozoic sequence separated by a Hercynian orogenesis from the Mesozoic-Tertiary sequence, folded at its turn by a set of Alpine orogenic movements.

The Paleozoic orogenesis was accompanied by a strongly developed regional metamorphic stage almost completely restricted to the Cambro-Ordovician, a late orogenic intrusive and a post tectonic volcanic phase. The sequence is well established, their stratigraphic dating, except the volcanic phase is poor.

The Alpine movements are stratigraphically well established and are largely restricted to the Mesozoic rocks, their influence on the Paleozoic of the axial zone is restricted mostly to faulting. A Pre-Cenomanian phase is accompanied by a peculiar metamorphism and intrusion of basic rocks along the North-Pyrenean fault system. Our description will go from old to young.

In the Paleozoic the best recognizable and dated horizon is the Silurian, a black shale complex dated by a graptolite fauna. The thick series below it are referred to as the Cambro-Ordovician, often but not everywhere strongly metamorphosed. The series above it consist of Devonian and Carboniferous.

From a structural point of view the units appearing on our sheets 1 and 2 are in the south a stretch of the axial zone of the Pyrenees, which by a complicated set of fault structures is separated from the northern external zone with the Paleozoic satellite masifs surrounded by Mesozoic rocks. They are from west to east (see map fig. 1) the Barousse, Milhas, Bouigane, Arize and Trois Seigneurs massifs. It are the satellite massifs which show the Hercynian regional metamorphism, the Cambro-Ordovician of the axial zone on both maps is almost completely devoid of it.

The subdivision of the Pyrenean mountain chain in an axial zone flanked by two external zones and two marginal troughs is obviously an Alpine feature, late-Cretaceous to Tertiary. As our work and these map sheets are mostly concerned with the Paleozoic rocks and their Hercynian history, this conventional subdivision is somewhat misleading. From the point of view of the Hercynian orogeny the metamorphic zone trending more from the SE to the NW represents the core, the axial zone of the orogene. It occupies almost the total of the exposed part of the eastern Pyrenees, the Aston and St. Barthélemy massifs on our sheets 3 and 5, and only the satellite massifs on the sheets 1, 2 and 4. The northern border of this Hercynian core is exposed only in the Arize massif and runs somewhere between the Mouthoumet and the Agly massifs (fig. 1).

CAMBRO-ORDOVICIAN

Below the Silurian black slates a formation of slates and quartzites crops out over a large surface on sheet 1 and a considerable surface in the Arize massif of sheet 2. From our maps no fossils from this formation have been recorded, but it is known that Caradoc Brachiopodes have been found in a shaly limestone near the top. Its bottom is unknown in our region and as no other fossil horizons are known, the name of Cambro-Ordovician seems the most reasonable term to refer to this series.

It consists mainly of slates, silty and sandy slates or phyllites, sandstones, quartzites and microconglomerates with a particular limestone bed and one or two conglomerate beds in the region of the Lez river. It often occurs in a regional metamorphic status both in the Arize and Barousse massifs (sheet 2) and in the southern part of Garonne region (sheet 1).

Its facies is typical of the neritic type, not a single horizon can be followed over long distances and consequently any detailed section has only a very local value. Pelites and psammites grade into one another both in vertical and horizontal sense, thicknesses between recognizable horizons vary considerably.

In fig. 2 three sections, one from the Garonne river, one from the Lez river and one from the Orle valley are compared, and it is obvious that no correlation can be made between the Garonne section and those of the Lez and Orle rivers. In the latter two sections both the upper conglomerate and the main limestone are present.

The upper shaly and sandy limestone of the Lez section of about 4 m thickness is really a calcarenite, often a well bedded alternation of quartzite and calcarenite beds of 30 to 60 cms thickness. It represents probably the same

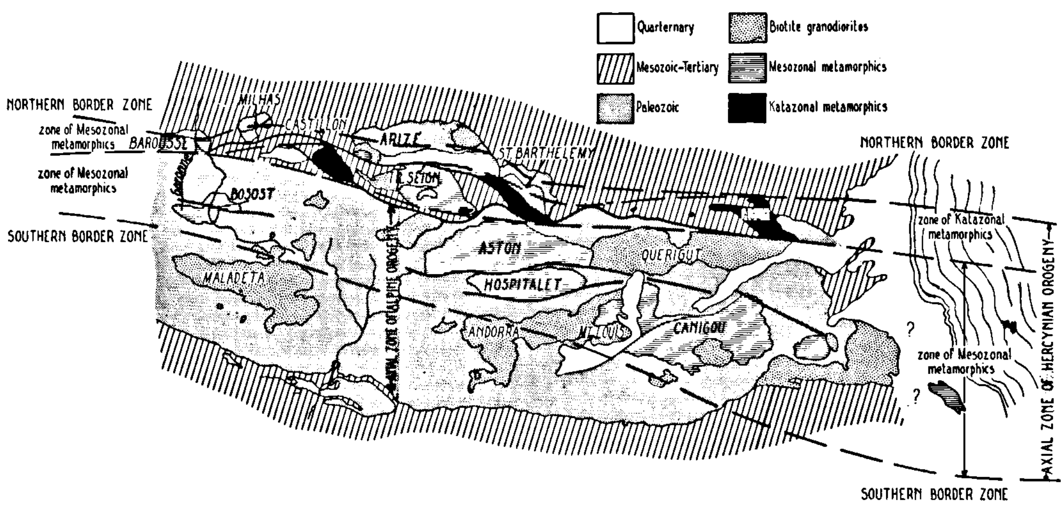

Fig. 1. The Pyrenean Mountain chain, with its Alpine and Hercynian axial zones

horizon as the fossiliferous slaty limestone of the eastern Pyrenees (Cavet 1959) which has been found also in the western part of the Barousse massif by Thiébaut (1957).

The thick, so called metalliferous limestone, wedges out between the Lez and Garonne river and is probably the same one as occurs in the St. Barthélemy and Aston massifs in the east. In the western Barousse massif (not on our map) Thiébaut (1957) found the same dolomitic limestone at about 500 m below the Silurian. It is absent in the Arize massif. In our region it has been marmorized and varies in colour from white to grey and even black. Locally it shows an erratic dolomitization and in the Bentaillou region it carries argentiferous lead-zinc sulphides, a metasomatic ore body. It often contains sandstone lenses, and its thickness varies greatly.

The upper conglomerate carries pebbles of up to 15 cm diam. of quartz or quartzite, sometimes even limestone pebbles. It does not form a fixed horizon, but occurs at variable distances below the Silurian or above the main limestone. A second conglomerate horizon is locally developed below the limestone in the Lez valley.

The total thickness of the exposed part of the Cambro-Ordovician is estimated at something between 1000 and 1500 m.

The regional metamorphism is almost wholly restricted to the Cambro-Ordovician rock series, and is much more developed in the satellite massifs north of the N. Pyrenean fault zone than in the axial zone. The grade of metamorphism ranges from the epizone to the catazone, from phyllites to gneisses.

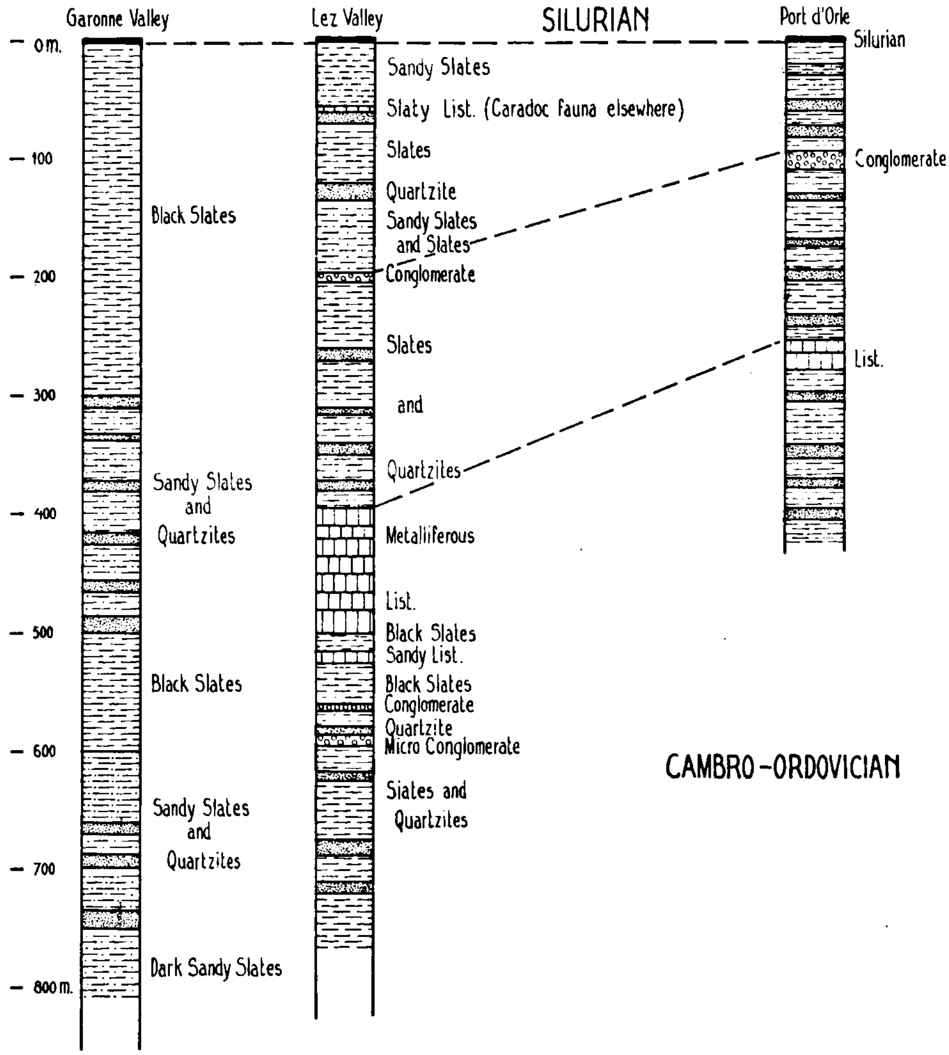

Fig. 2. Three sections of the Cambro-Ordovician

REGIONAL METAMORPHISM

Mica-schists and andalusite-mica-schists

In the Arize and Barousse massifs the phyllites grade downwards into mica-schists, usually containing biotite and muscovite. The phyllite series in the

Arize massif is very thick, but in the Barousse massif the metamorphic front has risen much higher and there mica-schists outcrop only a few hundred metres below the Silurian. Mica-schists are also to be found on the southern edge of sheet 1 in the northern part of the Bosost dome. These will be treated in another publication. In the Arize massif the biotite-schists grade into andalusite-cordierite-schists, but such aluminium-rich rocks have not been found in the Barousse massif, supposedly due to the character of the original sediment. A small isolated outcrop of andalusite-staurolite schists has been found along the southern border of the Oust granodiorite north of the Tuc de la Goulauze. It probably is a sliver brought up along the north Pyrenean fault originally belonging to the Trois Seigneurs massif. The same applies to the Silurian immediately north of this strip of schists.

Migmatites

Rocks belonging to the migmatite series occur in the Arize and Barousse massifs. In both massifs a twofold division into sillimanite-gneisses underlying the mica-schists and of quartz-diorites or migmatites as deepest exposed unit can be made. The transition between mica-schists and rocks of the migmatite series is gradational and represents a metamorphic front. A large exposure of quartz-diorites occurs in the central portion of the Lacourt granodiorite. Leucocratic gneisses and granites occur on a few places in the migmatites of the Arize massif; in the Barousse massif they form long sill-like bodies in the mica-schists.

Basal gneisses

The whole of the Castillon massif is made of rocks which on sheet 3 have been classified as basal gneisses. They are the highest grade rocks in the Pyrenees and are different from all other gneisses in this region. They are characterized by their abundance of garnet, a mineral which is uncommon in most of the metamorphics of the Pyrenees. A few different units have been distinguished in the Castillon massif. The rocks in the NW part of this area resemble those of the migmatite series which, like in the St. Barthélemy massif overlie the basal gneisses. Unlike all other satellite massifs in the Pyrenees a lower grade or non metamorphic cover is entirely absent in the Castillon massif.

Arize Massif

The western part of the Arize massif is in every respect similar to its eastern portion which has been described in the explanatory text to sheet 3 (De Sitter and Zwart, 1959). The same rock types in a similar succession occur in this area and for this reason they will be discussed only briefly. More details can be found in the above mentioned explanation.

1. *Mica-schists.* Downward the phyllites grade into biotite-bearing schists, a change which is accompanied by a general increase in grainsize. The attitude of the schistosity, frequently paralleling bedding, varies considerably. Locally it is steep as in the phyllites, elsewhere it is more flatlying. It may be assumed that in accordance with other areas in the Pyrenees such variation is due to secondary folding, but no systematic work on these variations has been done here thus far. With increase in grain size these schists usually develop a lineation determined by elongated mica flakes and with an E—W orientation. Microfolding

of the schistosity plane, either parallel or with an angle to the lineation occurs frequently.

Microscopically the schists consist of biotite, muscovite and quartz as main components, oligoclase as minor component and zircon, apatite, tourmaline and ore as accessories.

The thickness of the biotite-schists does not exceed a few hundred metres and downward they change rapidly into andalusite-cordierite bearing mica-schists. Both aluminium-silicates appear at approximately the same level. Near the boundary with the biotite-schists the crystals of both minerals are quite small but a few hundred metres deeper they occur as porphyroblasts up to several cm long and about one cm across. These long andalusites and cordierites are often aligned parallel to the lineation, determined by the oriented mica fabric. In thin sections perpendicular to this structural trend it became apparent that in the Arize schists many of these andalusites contain rotated trends of inclusions, testifying to their synkinematic origin and movements over the schistosity planes.

Staurolite and garnet have been found in a few schists of the andalusite zone. Fibrolite is common in the andalusite-schists near the boundary with the migmatites and here many schists carry andalusite and cordierite as well as fibrolite. It can be shown with the aid of thin sections that fibrolite has formed at a later date than the other aluminium-silicates, even at the expense of andalusite. In most cases, however, this mineral forms from biotite. Secondary crosscutting muscovite is also common in these schists. It may replace fibrolite and seems to be the latest mineral in the sequence.

As phyllites and biotite-schists, the andalusite-schists commonly show folded s-planes. In most cases the aluminium-silicates antedate these refolding phases as demonstrated by planar or spiral-shaped included schistosity. Reorientation or rotation of the aluminium-silicates in or parallel to the axial planes of the micro- and minor folds has been observed. Nevertheless crystallization had not ceased during at least one of these refolding phases as evident by the growth of new biotites parallel to the axial planes of the microfolds and the occurrence of polygonal arcs of micas.

Somewhere in the middle of the andalusite zone a layer of black andalusite or chiastolite bearing schists occurs. This layer can be followed over a distance of several kilometres and represents without any doubt a stratigraphic horizon. In view of its position in relation to the Silurian it is not excluded that this horizon is to be correlated with the so-called "série de Canaveilles" which has been described from the eastern Pyrenees by Cavet (1959). The Canaveilles series is characterized by the occurrence of black slates and schists associated with limestones or marbles. Limestones have not been found near this horizon in the Arize massif. However, in the Trois Seigneurs massif a horizon with both rock types lying considerably beneath the Silurian can certainly be correlated with the Canaveilles series. Its position with regard to the metamorphic front is somewhat higher in the Trois Seigneurs massif — near the top of the biotite zone — but it occurs roughly at the same distance beneath the Silurian. If the black schists of the Arize massif represent indeed the Canaveilles series, then the marble bands occurring in the eastern portion of the Arize massif near Arignac represent a much deeper stratigraphic level.

Three chemical analyses of mica-schists of the western part of the Arize massif have been executed. They show the following results:

SiO_2	56.61	57.55	59.02
TiO_2	0.96	1.11	0.95
P_2O_5	0.30	0.08	0.25
Al_2O_3	23.05	20.80	20.30
Fe_2O_3	2.89	3.12	4.16
FeO	5.88	5.12	4.37
MnO	tr.	0.06	tr.
MgO	1.60	2.50	1.29
CaO	0.80	1.91	0.64
Na_2O	1.36	2.47	3.22
K_2O	5.10	3.02	3.55
H_2O	1.88	2.41	2.61
	100.43	100.15	100.36

Analyst: Dr. C. M. de Sitter—Koomans

2. *Sillimanite-gneisses*. The andalusite-schists are at their turn underlain by rocks of the so-called migmatite series. It is true that migmatites are not restricted in the Pyrenees to this series and that typical migmatites also occur in other units.

The contacts of the schists with the migmatites is gradational and the change usually takes place within a distance of 10—20 metres. The sillimanite-gneisses are typical migmatites, usually of the veined type, biotite-sillimanite layers alternating with quartzo-feldspathic ones. Pods and irregular patches of quartzo-feldspathic material are also to be found and the frequent occurrence of concordant and discordant pegmatites is typical. The leucocratic layers consist of quartz and oligoclase with potassium feldspar and biotite as minor constituents. In the dark layers biotite and fibrolite are the major minerals. Sillimanite forms fibrous bundles, clearly growing at the expense of biotite. Cordierite has been found in many sillimanite-gneisses. Muscovite is present in small quantities always as crosscutting late crystals. Andalusite nor staurolite have been found in these gneisses, probably due to their higher metamorphic grade.

As far as small-scale structures are concerned, it should be remarked that the dark layers show a pronounced schistosity like that in the overlying mica-schists, but in the quartzo-feldspathic bands a preferred orientation of the minerals is usually lacking. This indicates that the rocks in an early stage were schists and that during some later stage the quartzo-feldspathic layers were introduced. For this reason the term migmatite is very appropriate using Sederholm's original definition. Lineations, abundant in the mica-schists, are usually absent in the migmatites and even the schistose layers rarely show elongated mica's like in the mica-schists. From these relations it can be deduced that the schistose layers are completely recrystallized during migmatization and that the preferred orientation of the mica's is due to mimetic crystallization after the original mica-schist. The same conclusion can be reached when the mineral association is considered. The original mica-schists consisted of biotite, muscovite, andalusite and cordierite as main components. In the schistose layers of the sillimanite-gneisses only biotite and cordierite occur, whereas primary muscovite and andalusite are altogether absent. Fibrolite clearly belongs to a late stage of crystallization and the crosscutting muscovite is the latest mineral in the whole sequence.

Extensive petrochemical work on these migmatitic rocks in the eastern part of the Arize massif has shown that the chemical changes taking place when mica-schists are converted to sillimanite-gneisses are very small indeed. Therefore the process of migmatization in these rock sequences is primarily one of metamorphic differentiation rather than injection of magmatic material or replacement with addition of silica and alcali's.

The thickness of the sillimanite-gneisses is very large in the eastern portion of the Arize massif but westward it becomes less and less so that on sheet 2 the thickness amounts to only a few hundred metres.

3. *Quartz-diorites.* The thickness of sillimanite-gneisses is determined by its lower boundary with the quartz-diorites, a metamorphic contact. These quartz-diorites have evidently formed from the sillimanite-gneisses by continued recrystallization and mobilization. The contact itself is always gradational: the light and dark layers become less pronounced, finally resulting in rather homogeneous and unoriented rocks which, however, are seldom homogeneous in large outcrops. They usually show the presence of layers and streaks of darker material, and inclusions of amphibolites and calc-silicate rocks often disrupted into small pieces are to be found in many outcrops.

Contrasted to the sillimanite-gneisses sillimanite occurs as rather large well-shaped crystals. Further constituents are quartz, oligoclase, potassium feldspar, biotite and muscovite. The latter mineral has formed rather late and does not belong to the main paragenesis. For more details we refer again to the explanation to sheet 3.

Chemical analyses of the quartz-diorites have shown that they are definitely enriched in silica and sodium although part of the original aluminium excess still remains. The strong recrystallization and mobilization are apparently related to the introduction of metasomatizing material (see also Mehnert 1960).

The mineralogical composition of these quartz-diorites is also indicative of their sedimentary origin; they often contain sillimanite and cordierite.

Concluding it can be said that the whole sequence of phyllite, biotite-schist, andalusite-schist, sillimanite-gneiss and quartz-diorite is one of progressive metamorphism and metasomatism, the quartz-diorites being the endmember in time as well as in grade and intensity. Nevertheless it is probable that the final product is represented by the intrusive biotite-granodiorites. This can, however, not be demonstrated since spacially, the intrusive granodiorites are no longer connected with the metamorphic sequence.

The described sequence occurs in most of the metamorphic areas of the Pyrenees for example the Saint-Barthélemy, Trois Seigneurs, Aston and Barousse massifs and shows everywhere the same succession in space and time.

The Castillon massif

The Castillon massif is in several respects different from the other Pyrenean gneiss massifs and therefore a somewhat more detailed description seems warranted. This massif consists entirely of high grade gneisses and a cover of mica-schists and unmetamorphosed Upper Paleozoic sediments like in the other north-Pyrenean massifs is absent.

Furtermore the gneisses are characterized by the abundance of garnet, a mineral which is uncommon in the Pyrenean metamorphics except for certain gneisses in the Agly and Saint-Barthélemy massifs. Like all north-Pyrenean massifs the Castillon massif is separated from the axial zone by a branch of the north-Pyrenean fault along which the Castillon massif is upthrown. On all other sides this area is bordered by Mesozoic sediments mainly in unconformable contact, except for a small occurrence of Carboniferous rocks near Loutrein probably in fault contact with the gneisses.

The Castillon massif itself reaches to about the same height as the Arize massif, the highest summit being 1823 m. Except for the main ridge the area is heavily forested and consequently rather badly exposed, making detailed mapping difficult. Only few rock types have been observed. Most of the area consists of a medium grained granitic to migmatitic garnet-gneiss with bands and inclusions of amphibolites and calcsilicate rocks with their boundaries parallel to the schistosity of the enclosing gneiss. The gneisses are often banded and locally the banding or the schistosity is strongly folded. An elongate outcrop of garnet-bearing leucocratic granite occurs east of the Cap de Bouirex and smaller outcrops of a similar rocktype may be encountered in other parts of the massif as well. Near Castillon itself, in the NW part of the massif the garnet gneiss changes into a migmatitic sillimanite-gneiss which in its turn grades into a more or less homogeneous quartz-dioritic rock, resembling the quartz-diorites of the Arize and Trois Seigneurs massifs. In the Castillon massif these sillimanite-gneisses and quartz-diorites are often garnet-bearing. In view of this resemblance it seems probably that these rocks are stratigraphically higher than the garnet-gneisses of the remainder of this area and that the succession in this respect is comparable to that of the Saint-Barthélemy massif, where a similar garnet-gneiss belonging to the basal gneiss-series is overlain by sillimanite-gneisses and quartz-diorites. The garnet-gneisses of the Castillon massif are classified in the basal gneiss series and since sillimanite-gneisses and quartz-diorites are still garnet-bearing they are also included in this series.

West of Alos near the Tuc d'Augaret and south of this point finegrained garnetiferous gneisses usually with a regular schistosity and no or only a faint lineation cover a relatively large portion of the massif. They have been marked on the map with a separate ornament. Due to the bad outcrops it was difficult to asses the relations with the normal gneiss, but it is believed that they grade into these. The existence of these peculiar finegrained gneisses has already been mentioned by Raguin (1938) who described them as "leptynites" and already compared them with the garnetiferous rocks of the Agly massif in the eastern Pyrenees. Unfortunately no further work by Raguin or other french geologists has been done in the Castillon massif.

The schistosity of the gneisses generally strikes WSW—ENE with a gentle dip of 0—30° to the NW, also indicating that the rocks in the northwestern part of the massif occupy structurally the highest position. In many of the migmatitic garnet-gneisses a more or less faint lineation due to parallel orientation of minerals is visible. Throughout the massif this lineation has a direction of N 40° W and a plunge of 0—30° to the NW (fig. 3). Besides these lineations minor folds in the same direction have been found in many places; in most of these folds the schistosity planes are folded and the folds are rather irregular. They change their shape rapidly and they resemble strongly the plastic flowfolds, so common in migmatites. Folds in other directions have also been observed but these are certainly less abundant. In many outcrops the schistosity does not show any folding and is planar. The finegrained gneisses also, do not display any folds. Amphibolites and calc-silicate rocks occur as more or less continuous layers with boundaries parallel to the schistosity of the enclosing gneiss. They do not exceed a thickness of a few metres. Marbles have not been found in the area although Raguin (1938) mentions one outcrop near Idrein SE of Castillon which also is marked on the French geological map sheet Bagnères de Luchon. Only calc-silicate rocks have been found in this part of the area. Most of the amphibolites and calc-silicate rocks are schistose or foliated; some are also linear.

Only the most important ones are recorded on the map and many more occur throughout the area. Their presence is good evidence that the basal gneisses of the Castillon massif are of sedimentary origin.

Study of several thin sections revealed that most of the migmatitic and finegrained garnet-gneisses always contain the following minerals: quartz, oligoclase, biotite and garnet (almandine) with zircon, apatite, rutile and magnetite as accessories. In addition potash feldspar may be present though usually in small, sometimes in larger quantities; it seems to be somewhat more abundant in the finegrained gneisses. Further sillimanite, cordierite, hypersthene and andalusite have been observed in a number of gneisses.

As a rule oligoclase occurs as crystals up to ½ cm in diameter. In few cases it is antiperthitic; alteration into sericite or muscovite is rather common. In some sections, especially those parallel to the lineation, the plagioclase is eye-shaped with quartz and biotite filling the space between the feldspars. This augen-structure is, however, rather faint in most sections and often it has vanished altogether, probably as a result of static recrystallization. In the well developed augen-gneisses quartz and biotite may show the effects of strain as undulatory extinction and bent crystals.

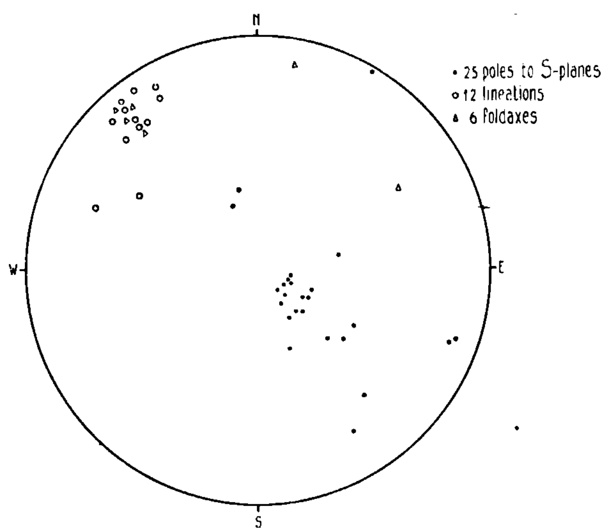

Fig. 3. Stereogram, showing poles to S-planes, lineations and foldaxes in basal gneisses of Castillon massif

Garnet occurs as crystals varying in size from less than one to more than 10 mm. It is ellipsoidal or flattened in sections parallel to the lineation and normal to the schistosity. Cracks filled with biotite and usually oriented at right angles to the schistosity are very common. They probably indicate that the minerals are flattened in a direction perpendicular to the schistosity resulting in tension cracks. Similar fractures with biotite occur in the garnets of the basal gneisses of the Saint-Barthélemy massif.

Cordierite has been found in a few sections; it occurs as crystals of a few mm size and is often partially or completely chloritized. Sillimanite is a rather common constituent; it builds fairly large prismatic crystals. In some sections a very large amount of sillimanite has been found, for example west of Sentenac where coarse-grained gneisses occur with garnets up to several cm in size. In the matrix large bundles of sillimanite crystals are wrapped around the big garnets.

Hypersthene, although not very common, has been found in gneisses from several different localities throughout the massif. It seems to be somewhat more frequent in the finegrained gneisses.

It occurs as crystals up to several mm in size. Hypersthene has not been found in rocks with sillimanite or cordierite. Andalusite has been observed as a minor constituent in a few rocks. Mention should be made of the occurrence of large zircon crystals in the basal gneisses. They are short prismatic and may attain a length of 0.25 mm. Similar large zircons have also been found in the basal gneisses of the Saint-Barthélemy massif. Their presence may be due to a special kind of sediment in this zone, later on metamorphosed to the basal gneisses.

The presence of cordierite, sillimanite and hypersthene and the absence of primary muscovite in the basal gneisses indicates that these rocks were metamorphosed under catazonal conditions like the gneisses of the Saint-Barthélemy and Agly massifs. The presence of garnet and hypersthene points to conditions close to that of the granulite facies although biotite is too common to attribute these rocks to the real granulite facies. They probably fit best in the newly erected Hornblende-granulite facies (Turner and Verhoogen, 1959).

About twenty thin sections of calc-silicate rocks and amphibolites occurring in the basal gneisses have been examined. They show a variation in composition within certain limits; transition of these rocks to normal gneisses have not been found. Pure marbles seem to be almost absent. In many thin sections at least two successive mineral assemblages are present, a primary high grade one with minerals like calcic plagioclase, green or brown hornblende, hypersthene, diopside, garnet, and a lower grade one clearly replacing to a smaller or larger extent this first assemblage. This secondary association consists of clinozoisite, cummingtonite, muscovite, calcite and colorless amphibole.

The following types can be distinguished: 1) amphibolite with labradorite-bytownite, green hornblende and minor quartz and biotite; 2) pyroxene-bearing amphibolite with bytownite, browngreen hornblende, hypersthene and/or diopside; 3) finegrained hornblende-gneiss with bytownite, green hornblende and quartz; 4) finegrained diopside-gneiss with bytownite, diopside, quartz and garnet. Common accessories in all these rocks are zircon, apatite, rutile, magnetite. In one amphibolite primary cummingtonite was found, but elsewhere this mineral is a common alteration product of pyroxene or green hornblende. Bytownite is frequently altered into clinozoisite; less frequently into muscovite or calcite. Colorless amphibole as replacement of green hornblende has been encountered a few times.

Undoubtedly the variety of these rock types will increase when more thin sections are cut; nevertheless the mineral assemblages of these rocks confirm the high grade character of the metamorphism typical of the basal gneisses. The formation of retrograde minerals like cummingtonite, clinozoisite, calcite and muscovite must be due to a late phase of metamorphism, which is hardly reflected in the garnet-gneisses, probably due to their smaller sensitivity.

There can be no doubt that these gneisses are related to the basal gneisses of the Saint-Barthélemy massif and similar rocks in the Agly massif in the eastern Pyrenees. They show the same high grade mineral assemblage and the same structures, mainly characterized by lineations and folds in approximately N—S direction, in strong contrast with the E—W strike of the Paleozoic structures of the axial zone. Previously this has lead to the idea that the basal gneisses form an older basement on which the Cambro-Ordovician sediments have been laid down and subsequently metamorphosed to gneisses and schists. Although this hypothesis cannot be discarded completely until radiometric age determinations have been done, we assume that the basal gneisses belong to the Hercynian orogenic cycle. The deviating structures should then be due to another phase of deformation later than the E—W main folding. It deserves mention that in the Bosost dome in the Valle de Aran an important synmetamorphic folding phase with N—S structures has been detected which tentatively can be correlated with the structures in the basal gneisses. The metamorphics of the Bosost dome are however not as high grade as those of the North-Pyrenean gneiss massifs. Why such highgrade rocks are restricted to these areas and do not occur in the axial zone, remains to be explained, but they certainly contribute to the peculiar character of the North-Pyrenean fault zone.

Barousse massif

A detailed account of the geology of the Barousse massif has recently been published by J. Thiébaut (1957). Although his map differs from ours in several respects, the main rock divisions and their location are essentially the same on both maps.

The sequence of metamorphic rocks in the Barousse massif is similar to that of the Arize massif and the same types of rocks are to be found in both area's. Garnetiferous gneisses like those in the Castillon massif are altogether absent. From top to bottom this sequence reads: Cambro-Ordovician phyllites, mica-schists with layers of a leucocratic gneissose granite, migmatitic sillimanite-gneisses and more homogeneous quartz-dioritic rocks, on the map referred to as migmatites. The latter two units correspond to Thiébaut's "migmatites hétérogènes" and "migmatites fondamentales". Pegmatites occur throughout the migmatite series often as crosscutting dykes. Marbles and amphibolites have been encountered rather frequently, the most important ones are shown on the map.

The rocks attributed to the Cambro-Ordovician show the same characteristics as those of the Arize massif; they are phyllites with intercalated quartzites usually showing minor and microfolds of the cleavage and a secondary crenulation cleavage. There seems to be no reason to subdivide these phyllites into "mica-schistes supérieurs" and "Ordovicien schisteux" as advocated by Thiébaut; there is no visible difference. Downward the phyllites grade into biotite-schists which become coarser grained toward the migmatite boundary. The mica-schists contain biotite, quartz, some muscovite often as crosscutting crystals, plagioclase, potash feldspar in minor amounts and zircon, apatite, tourmaline and ore as accessories. Interbedded in the schists occur a few amphibole-schists with actinolitic amphibole and quartz, apparently representing a more calcareous sediment. Schists with aluminium-silicates, like andalusite, cordierite or staurolite, so abundant in most metamorphic area's of the Pyrenees seem to be lacking in the Barousse massif. This is probably due to the type of sediment which must have been less rich in aluminium than usual. The thickness of the biotite-schists is approximately 500 m. In these schists near Chaum and west of Estenos several sills of a leucocratic homogeneous gneissose granite occur, which can be traced over large distances. These rocks consist of the following minerals: quartz, albite, potash feldspar, biotite and muscovite with some minor garnet. In most thin sections the texture is more or less unoriented but in a few an evident augen texture has been found. In other sections the plagioclase is subhedral and shows beautiful idiomorphic oscillatory zoning which might indicate a magmatic origin. The occurrence of augen-gneiss textures suggests that they may be compared with the leucocratic augen-gneisses of the Saint-Barthélemy and Aston massifs. In the Barousse massif the original texture may have disappeared due to static recrystallization and in this context it should be remarked that also the enclosing schists are strongly recrystallized as shown for example by the decussate intergrowth of mica's and the occurrence of polygonal arcs of mica flakes in microfolded schists. At any rate the origin of these sills remains rather obscure, whether emplaced by magmatic intrusion or metasomatic replacement.

Typical migmatitic sillimanite-gneisses are exposed in a band between the Pique and Ourse rivers near the "Sommet d'Esclète" and also as small bodies in the underlying migmatites. The most characteristic rock is a banded gneiss consisting of alternating layers of quartzo-feldspathic material and biotite-fibrolite giving the rocks their schistose appearance. As in the other gneiss massifs of the Pyrenees the quartzo-feldspathic bands have an unoriented structure. Besides the mentioned minerals, they contain potash feldspar, muscovite and sometimes cordierite. The rocks are entirely similar to the sillimanite-gneisses of the Arize, Trois Seigneurs and Saint-Barthélemy massifs and for more details we again refer to the explanation of sheet 3. As far as the origin of these rocks is concerned there can be no doubt that they are derived from sediments as ascertained by the occurrence of quartzite and calc-silicate layers. According to Thiébaut the abundance of sillimanite in these rocks is due to the transfer of aluminium from deeper layers which have been more completely granitized, towards the upper boundary of the migmatite complex so as to form an aluminium front. Although this is an interesting hypothesis, Thiébaut does not support it with the necessary petrochemical investigation. Since we have done extensive work on this problem with similar rocks of sheet 3 we are in a position to evaluate this hypothesis for the Barousse massif. Our conclusions for the sillimanite-gneisses of sheet 3 was that little chemical change had occurred during the transformation of phyllites or mica-schists into sillimanite-gneisses, but that some transfer of aluminium from deeper to higher levels may have taken place. However, to consider all sillimanite as a product of metasomatism, seems to go too far, and probably a large portion of the necessary aluminium was derived from the original sediment.

The deepest exposed unit in the Barousse massif is on the map referred to as migmatites, which means migmatites s. l. Indeed this unit is much more inhomogeneous than the quartz-diorites underlying the sillimanite-gneisses for example in the Arize massif.

Unoriented quartz-diorites occur frequently but schists, sillimanite-gneisses and biotite-gneisses are widespread in this zone. Concordant and discordant pegmatites, marbles, calc-silicate rocks and amphibolites are also common throughout this deepest part of the Barousse massif. A detailed map of the hill called "Le Pujot" east of Marignac between the Pique and Garonne rivers, mapped by Vlierboom shows the complexity of this lower zone (fig. 4). Biotite-gneisses and migmatites form here the framework with some marble and amphibolite bands as an ancient stratigraphic horizon running through this area. A swarm of late crosscutting pegmatite dykes is one of the salient features.

The quartz-diorites are mainly composed of quartz, sodic plagioclase, biotite, potassium feldspar and subordinate sillimanite, cordierite and muscovite. Most of the gneisses in this zone show a similar composition but instead of an unoriented texture they show a more or less pronounced schistosity. Aluminium-

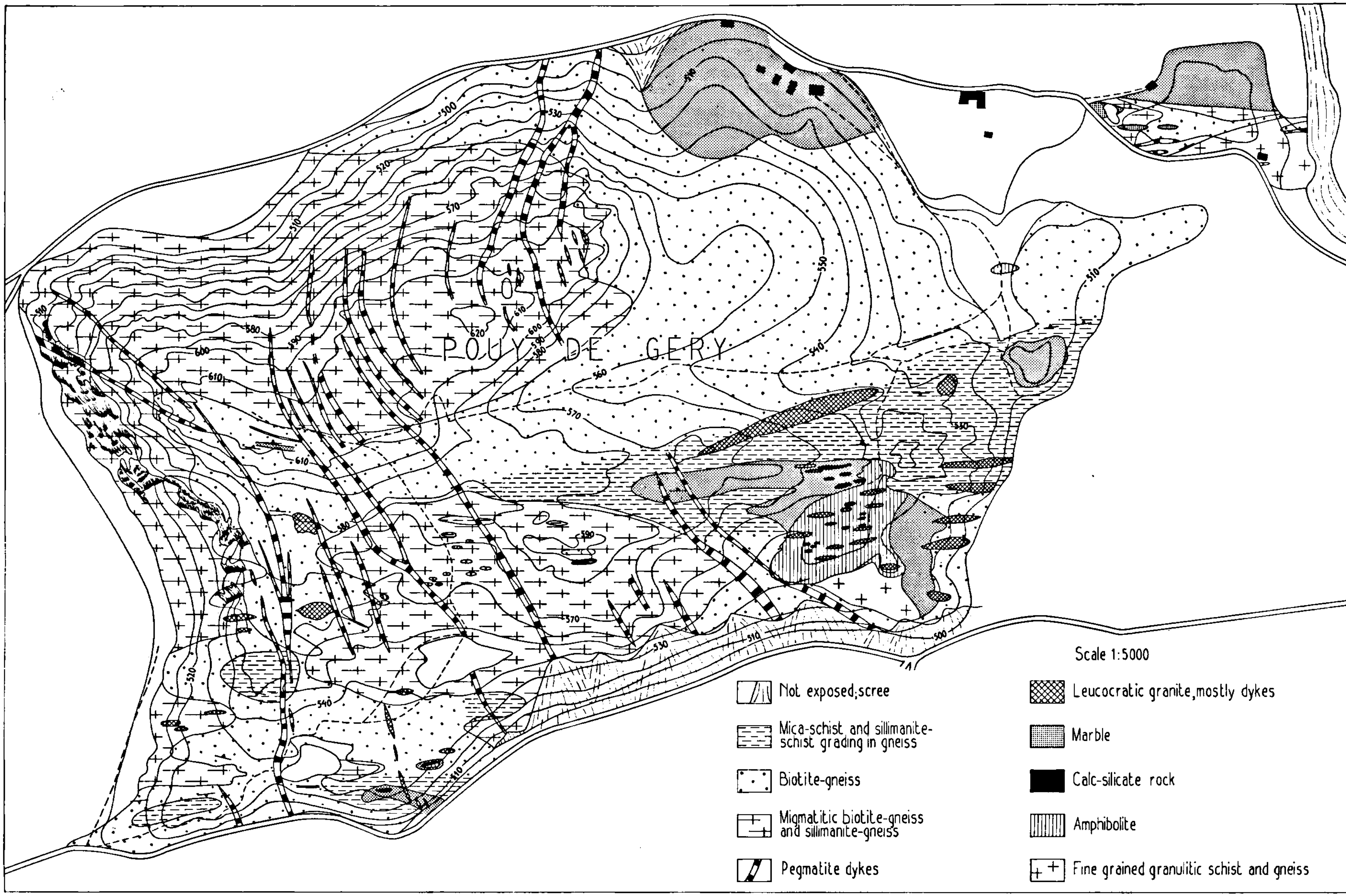

Fig. 4. Geological map of the „Pujot" hill, east of Marignac

silicates like sillimanite and cordierite are definitely less abundant in this zone than in the sillimanite-gneisses of the Barousse massif and in similar quartz-dioritic rocks from other migmatite areas in the Pyrenees. Presumably this is due to a less pelitic original sediment.

As shown on the map marbles and amphibolites occur at several localities in the Barousse massif. Associated calc-silicate rocks are common. Marbles have only been found in the deepest exposed migmatites for example in the Pujot hill and south of Eup where they form one horizon. The rocks consist of a matrix of calcite in which round crystals of basic plagioclase (andesine to bytownite), diopside, titanite, humite and quartz, and long prisms of tremolitic amphibole occur. Plagioclase and diopside may be altered to clinozoisite. Associated with these marbles are calc-silicate rocks containing no or only little calcite and further basic plagioclase, potassium feldspar, quartz, diopside, green hornblende, titanite and biotite as primary constituents. Alteration products are clinozoisite, epidote replacing plagioclase, diopside or hornblende, scapolite (mizzonite) growing at the expense of plagioclase, and pale green amphibole. Most of these rocks show little signs of preferred orientation of minerals, probably as a result of static recrystallization.

Amphibolites have been found near Chaum and south of Estenos. They are characterized by the complete absence of schistosity and lineation, a property which is also evident under the microscope. They contain green or palegreen hornblende growing at random, sodic plagioclase (oligoclase-andesine), some quartz and accessory titanite. Amphibole-schists composed of lightgreen amphibole and quartz have been found near Chaum.

An interesting outcrop occurs south of Chaum along the highway St. Béat-Chaum. Here hornfelsic schists are lying as more or less rounded fragments in a granitic matrix. Closer inspection reveals that the faintly visible schistosity of the schists has the same position in all fragments and that consequently they are not displaced or rotated during the emplacement of the granitic rocks. The boundaries between schist and granite are often sharp, sometimes gradational. Some thin veinlets penetrate the schist ending in a row of separate feldspar crystals. It seems probable that the granite is a replacement product leaving a number of schist remnants undisturbed. In view of the very incomplete granitization of the whole of the Barousse massif this seems in good agreement. The schists of this outcrop are somewhat calcareous (see also chemical analysis). They contain plagioclase, quartz, biotite and sometimes a little hornblende and clinozoisite-epidote. The plagioclase is oligoclase or andesine, sometimes more basic in the cores of zoned crystals. It occurs in large quantities, usually exceeding those of quartz. It is seldom twinned. Quartz builds small crystals and may be only a minor constituent. Biotite occurs as small flakes and does not usually show preferred orientation. In most schists it also forms glomeroblastic aggregates with a flattened shape and indicating the faint schistosity. The crystals forming the glomeroblasts have an unoriented decussate intergrowth. The schistosity must be considered as a relict texture which has lost its character by static recrystallization, a feature also found in other rocks of the Barousse massif.

The granitic rocks are in fact quartz-diorites consisting of quartz, oligoclase and biotite with occasionally some potassium feldspar, tourmaline, epidote and accessory zircon, apatite and ore. Plagioclase builds hypidiomorphic crystals often in two distinct sizes. Large crystals up to 4 mm in size tend to an euhedral shape; they are often zoned with 2—3 zones and somewhat more basic cores; the zones are rather faint but their boundaries are idiomorphic. The borders of the crystals themselves are crenulated. Small drops of quartz and crystals of biotite are commonly enclosed in the plagioclase. Smaller but more abundant plagioclase crystals are usually subhedral and may or may not show zoning. Sometimes the plagioclase is antiperthitic. Quartz occurs as irregular crystals between the plagioclase; biotite builds subhedral plates. The texture is unoriented and typically crystalloblastic.

The boundaries between schist and quartz-diorite may be sharp or vague. In the schists close to the contacts porphyroblasts of quartz and plagioclase similar to those in the quartz-diorite are of common occurrence. Some biotite glomeroblasts occur in the quartz-diorite. Thus microscopic properties seem to support the replacement origin. These replacement breccias as they should be called, resemble closely similar breccias described by Goodspeed from N. E. Oregon (U. S. A.).

In order to evaluate the chemical changes during the transformation of schists to quartz-diorite two chemical analyses, one of each rock type have been executed by Dr. C. M. de Sitter-Koomans, showing the following results.

	schist	quartz-diorite
SiO_2	54.48	71.50
TiO_2	1.44	0.09
P_2O_5	0.18	0.20
Al_2O_3	18.01	15.18
Fe_2O_3	1.75	0.51
FeO	6.25	1.03
MnO	0.07	0.02
MgO	5.09	1.03
CaO	6.03	3.02
Na_2O	2.95	6.04
K_2O	2.70	1.24
H_2O	1.58	0.48
	100.53	100.34

It is evident that the quartz-diorite has a larger amount of silica and sodium and a smaller amount of iron, calcium and potassium. If the assumption is correct that this is a replacement of schist by the quartz-diorite then an introduction of silica and sodium and removal of iron, calcium and potassium must have taken place. It should be remarked that similar chemical changes have taken place in the transformation of schists to mobilized quartz-diorites in the Arize, Trois Seigneurs and Saint-Barthélemy massifs.

Like in the other metamorphic areas of the Pyrenees it is possible to make at least a twofold division of the metamorphic history which is well substantiated by the work of Guitard and the authors. There is an early phase of metamorphism contemporaneous with strong deformation making in general schistose and linear rocks like phyllites, mica-schists and augen-gneisses and a late phase with no or only a weaker and different kind of deformation during which crystallization in general did not produce preferred orientation of minerals; in general earlier schistosities and lineations tend to disappear during this phase of static recrystallization. Although detailed field and microscopic work usually allows the recognition of more phases of folding and metamorphism, like in the Aston massif (Zwart 1960) and the Bosost dome (Zwart 1962) such work has not been done in the Barousse massif. Anyway two phases are clearly recognizable in this area, the first phase producing phyllites and mica-schists and possibly also the leucocratic gneissose granitic sills in these schists. The second, static phase is responsible for the migmatization, as testified by the unoriented fabric of many migmatitic and quartz-dioritic rocks. The schistosity of the sillimanite-gneisses is a relict of the original mica-schist. This phase of static crystallization has also attacked part of the overlying schists. Calc-silicate rocks and amphibolites show also the results of this feature. In general it can be remarked that in the Barousse massif this second phase of recrystallization was rather strong and in most thin sections its effect is clearly visible. The migmatization itself is far from complete and seems to be less strong than for example in the Arize and Trois Seigneurs massifs.

It should be remarked that this phase of recrystallization is intimately related to the migmatization itself and fundamentally different from an intrusive granite with its contact aureole. Hence the attribution of certain rocks in the Barousse massif to a contact aureole, as has been done by J. Thiébaut, is uncorrect and misleading.

SILURIAN-DEVONIAN-CARBONIFEROUS

Silurian

The Silurian is present in its classic facies of black slates, which occurs over a much wider area than the Pyrenees, from the Cantabric Mts in the west, in Cataluña in the south and in the Montagne Noire in the north. The black colour is generally thought to be derived from a high graphite content, but chemical and röntgenographic analyses proved that even with a content as low as 0.5 % of Carbon the slates have the same powdry black colour which stains the fingers. Part of the black colour might be due to finely disseminated iron-sulphide, which is common also in these black schists as pyrite crystals. The slates are very fine grained, may have an exceptionally high aluminium content (up to 35 % Al_2O_3) and a very low quartz content. The iron content of 7—8 % Fe_2O_3 is not exceptionally high for a slate but as much of the iron occurs as sulphides it is easily soluble in water and the frequent water sources in this formation are characterized by the sulphurous rust coloured film they deposit on the stones and in the beddings of its rivulets.

The top part of the slates (upper 30—50 m) carries black limestone layers, lenses or nodules, which have frequently delivered *Orthoceras* and *Cardiola interrupta*. Sometimes the limestones are coarse grained and of lighter colour. They form the transition to the Devonian limestones and calcareous slates.

Graptolites are frequently found in the less disturbed parts of the Silurian, predominately *Monograptus species*. They range in age from Middle Llandovery to Lower Ludlow.

The richest outcrops are round Sentein, Irazein, Lascoux and Luentein. Their fauna has been described by Roussel (1892, 1893—94), Caralp (1888), Barrois (1896), Carez (1905) and Frech (1897—1902) replenished by some of our own determinations.

They have the characteristics of the assemblages of some of the Elles zones (1925).

Nilssoni zone (zone 33 of Elles) Ludlow with *Monograptus bohemicus, M. colonus, M. Nilssoni* and *M. Roemeri.*

Riccartonensis zone (zone 27) and *Murchisoni zone* (zone 26) with *Retiolites Geinitzianus,* L. Wenlock.

Turriculatus zone (zone 22), Upper Valentian, with *M. Becki* and *M. runcinatus.*

Convolutus and *Gregarius zones* (zones 19 and 20), Lower Valentian, with *Rastrites peregrinus, Monograptus lobiformus, M. communis, Petalograptus palmeus.*

Because a trustworthy relatively undisturbed sequence of the Silurian on top of the Ordovician and below the Devonian is unknown anywhere in the northern Pyrenees we can not conclude from this fossil evidence that the Lower Llandovery and the Upper Ludlow and Downtonian are missing. Moreover neither the lithostratigraphic top of the Ordovician nor the lithostratigraphic base of the Devonian carry any fossils. The only warranted biostratigraphic conclusion is that the black graphite slates facies of the Silurian reaches from the Middle Llandovery to the Lower Ludlow inclusive. Both its lower and upper limits have a transitional character, a transition to ordinary dark coloured slates of the Ordovician and to calcareous slates or limestone of the Devonian. Therefore it is not probable that there occurred any interruption of sedimentation either at the bottom or at the top of the Silurian, but positive evidence of biostratigraphic nature is missing.

The black slates of the Silurian are an extremely incompetent kind of rock and therefore they have become the detachment horizon of disharmonic folding between the Devonian-Carboniferous structures on top and the Ordovician structures below.

Thermal metamorphism generates chiastolite in the black slates.

Devonian

The development of the shale-limestone sequence of the Devonian after the uniform Silurian slates, is very variable both in thickness and in succession of lithostratigraphic units. Fossils are very rare and have not been found between the massif d'Arize occurrences and those of the Pique valley described recently again by Destombes (1953).

Generally a lower and upper part of the Devonian can be distinguished, the lower part having shales and limestones, the upper part a multicoloured nodulous limestone, "griotte" in french terminology. In the Lower Devonian we find an alternation of shales or slates, shaly limestone and limestone sometimes with secondary dolomitization. The most detailed section available is that south of Couflens in the Salat-Escorse region described by Zandvliet 1960. It is some 1000 m thick and the top is unknown. The same sequence between the Silurian and the griotte is certainly much thinner north of Couflens and in the Lez valley some 400 m have been measured, but the base of the griotte has not quite been reached, in Marignac it is some 400 m thick, in the Hte Garonne, west of the Pique valley, only 250 m (Destombes) (see fig. 5). The three sections have the general distribution of slate and limestone in common, a more slaty upper and lower section, each some 100—150 m thick and a 50—100 m more calcareous sequence in the middle. This succession continues to the west with the same general caracteristics beyond the Ourse river. This is remarkably like the Arize massif section, and both there and in the Hte Garonne the middle Devonian fauna has been found near or in this central limestone. This middle Devonian limestone is characterized by its dark colour and spatic crystallization (calcaire à entroques) from the St. Barthélemy massif to west of the Ourse river. Compared with the twice as thick section of the upper Salat region (± 1000 m, Zandvliet 1960), in which 5 or 6 distinct limestones at regular intervals with a basal limestone at the bottom of the whole series have been recognized, the difference is striking. The same striking difference is observed when we compare our set of northern Devonian sections with that of the Valle de Arán, where a large part of the section is occupied by sandstones (Las Bordas sandstone, Kleinsmiede, 1960).

According to Zandvliet this boundary between a northern and a southern section is rather sharp and runs along the Couflens Silurian zone in the Salat river and when we continue this sharp boundary line towards the west it forms also the boundary between our Lez-Garonne section and the Valle de Aran section.

In our northern Lower Devonian section the thickness diminishes towards the west, and the limestones become less pronounced. Near its southern boundary the first basal limestone typical for the Valle de Aran appears both in the Garonne section and in the Lez and Salat regions.

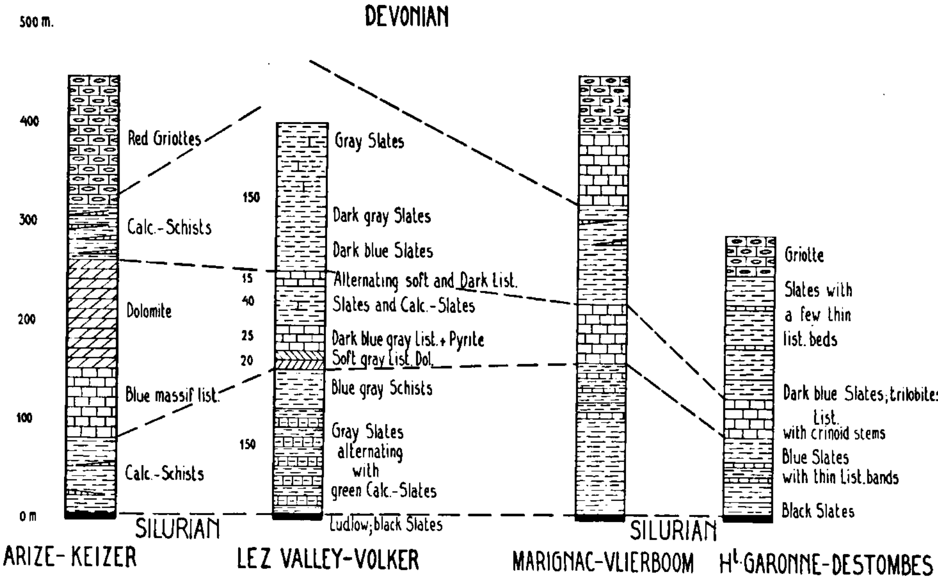

Fig. 5. Four sections of the Devonian sequence

The Upper Devonian is formed by the nodulous limestone facies, the griottes. There always is a transitional series between the slates of the middle section and the griottes in which a quick alternation of slates, limestone and griotte layers of various thickness occur. These slates are often black.

The outcrops of the Upper Devonian and Carboniferous are almost wholly constricted to the northern limit of the axial zone and to the Arize and Bouigane massifs. The largest development occurs in the Estours valley. As everywhere else the nodules of the griotte facies consist of very fine grained limestone and the matrix of a fine grained pelite. Stylolites are common. In some cases the nodulous habit is certainly of tectonic origin, then there is one cross section rounded, both other ones are linear (Estours quarry, see chapter on tectonics) the original rock being a quick alternation of thin pelite and limestone layers. Often the nodules are really synsedimentary and sometimes the nodules are simply goniatites.

The rock is often used and quarried for its beautiful colours, the nodules being white, green or red, the pelite of a darker colour red, violet red or dark green.

When a good section could be measured the thickness varied between 120 and 170 m.

Keizer, 1954, described coarse limestone conglomerates on top of the Upper Devonian, they have been found also in the Barthélemy massif (Zwart 1953) and in the Ax-Montcalm massif (Allaart) and by Ovtracht 1956 at different points. The top of griottes becomes occasionally siliceous thus forming a transition horizon towards the overlying Carboniferous cherts, and in the Arize massif there occurs a repetition of the griotte facies in the Carboniferous. The supposition of an unconformity between the Upper and Middle Devonian, originally suggested by de Sitter 1951 has not been confirmed but local post-Devonian emergences seem to be certain. (Ovtracht, 1956). Fournié, 1956 introduces a karstification of the Devonian limestone before the deposition of the Carboniferous cherts, accompanied by manganese ore deposition in the north Pyrenean zone.

Dolomitization can occur in any of the Devonian limestones and is often very irregular. When it attacks the red griottes they are completely discoloured and often a sharp line separates the dolomitized and non-dolomitized parts. The dolomite of the Middle Devonian is rather a continuous horizon (Keizer, 1953) and is perhaps syngenetic (Pélissonnier, 1959).

Carboniferous

Carboniferous rocks occur along the north Pyrenean faultzone and in the satellite massifs of Arize and Bouigane. At the base we find generally, but not everywhere, a chert horizon of some 20—50 m thickness followed by series of alternating shales, silts and sandstones with the shales predominating. Limestone beds are relatively rare.

The chert layer represents an important litho- and bio-stratigraphical key horizon. It consists of well bedded black chert of 0—50 m thickness alternating with thin friable black mudstone often containing phosphate, $Ca_3(PO_4)_2$, nodules of $\pm$ 5 cm diam. Its fossil content consists of Radiolarites, Orthoceras, Goniatites and plant remains. The chert is very finely stratified, the phosphate nodules occur chiefly in the lower part, the upper part shows a transition towards ordinary shales by an increase of thickness and frequency of the mudstone intercalations. The Goniatites indicate a Lower Visean age (Delépine, 1935). The chert horizon reposes generally with a sharp and distinct contact on the Upper Devonian griotte sometimes with a shale layer at its bottom. Apparently the Tournaisian is therefore missing and probably also the upper part of the Famenian. Sometimes, the boundary is not so sharp, the Upper Devonian limestone becomes silicified, has no longer a nodular aspect and occasional chert layers appear and form a transition to the overlying chert. This chert horizon at the base of the Carboniferous is very widespread and can be followed from Cantabria and Asturia through the Pyrenees to the Montagne Noire and further east to Germany, always resting on the Devonian (von Gaertner, 1937). Whether during the Tournaisian there really was a general emergence explaining the biostratigraphical hiatus remains doubtful, particularly so because lately conodonts of Tournaisian age have been found both in the Pyrenees and in the Montagne Noire (Ziegler, 1959). On the other hand the presence of limestone conglomerates in the Upper Devonian and the karstic pre-Carboniferous weathering of the griottes and the filling up with manganese ores of the cavities (Ovtracht et Fournié, 1956, Fournié 1956, Lougnon, 1956) proves that in the Arize massif at least there was a local emergence. The ecological circumstances of the chert horizon with phosphate nodules, goniatites, radiolaria and plant fragments remains enigmatic.

Often the chert layer is missing and the Devonian griotte is covered directly with shales of the Carboniferous, sometimes with a fine grained breccia containing chert fragments intervening. This breccia also occurs on the top of the cherts in the Estours-Salat region, it has a shaly matrix.

A little above the chert there often occurs a thin band of limestone, always siliceous, often of nodular aspect, varying in thickness from 1 to 5 m. This horizon is well known also in the Montagne Noire; here it occurs in the Arize massif, in the Salat-Estours region and west of Cierp, but it is absent west of St. Béat.

The principal rock types above the chert horizon are shales or slates with greywackes and sandstones. Both are micaceous. The graywackes carry felspar fragments and in the region between the Gers river and the Garonne even pebbles of max. 2—3 cm diameter. These latter rocks often show beautiful slumpstructures in which the pelitic and psammitic rock types have been mixed. Further to the west, outside our region a thick limestone with Productus has developed. The total thickness of this shale-sandstone series is unknown, because it is always covered unconformably by the Triassic, but the exposed thickness can reach as much as a 1000 m.

Fossils are very rare and practically only known from the Arize massif, where two fossiliferous outcrops occur, only some 30—50 m above the chert, one near Mondette (St. Girons) the other further east near Larbont, containing goniatites and brachiopodes (Productus) indicating an Upper Visean age. The most common goniatite is: Goniatites subcircularis, further G. granosus, G. falcatus, Prolecanites quinquelobus, Daraelites praecursor var. pyrenaicus. (Delépine, 1935.) It is not improbable that a large part of the shale sandstone series belongs to the Westphalian. The facies is certainly near shore (plant remains, slumps, micaceous habit) not deep water and as such announces the approach of the late Carboniferous folding, which can be dated only in the southern Pyrenees (probably pre-Upper Westphalian, certainly pre-Stephanian) and in the Mouthoumet massif (pre-Stephanian), but not here, where it is the Trias which covers unconformably the folded Paleozoic rocks.

LATE CARBONIFEROUS INTRUSIVE ROCKS

(For the Oust granodiorite, see explanatory text to sheet 3)

The Lacourt Granodiorite

In the westernmost portion of the Arize massif occurs a biotite-granodiorite which on the map is clearly discordant with regard to the phyllite-micaschist-migmatite series. This granodiorite is fully comparable to the Foix, Trois Seigneurs and Auzat granodiorites, described in the explanation to sheet 3. They are considered to be intrusive magmatic rocks. For the Lacourt granodiorite this is demonstrated by the occurrence in lowgrade phyllites (so-called disharmonious granites) usually with sharp contacts, the presence of a typical contact metamorphic aureole, the homogeneity and typical igneous textures.

The granodiorite is a medium grained lightgray rock, usually massive in outcrop and handspecimen, and very homogeneous except for a few basic clots.

Microscopically the rock consists of quartz, plagioclase (calcic oligoclase to andesine), microcline and biotite as main constituents. Green hornblende, although not frequent in most other Pyrenean granodiorites, is rather common in the Lacourt stock. Zircon, apatite, magnetite and ilmenite are the common accessories.

Plagioclase occurs as sub- to euhedral crystals, often strongly oscillatory zoned with more basic cores, and constituting 30—50 % of the rock. The mineral is often strongly sericitized. Quartz and microcline occur interstitially whereby microcline usually is in the minority. Frequently it partially replaces plagioclase. Biotite and hornblende build hypidiomorphic crystals and are often chloritized.

South of the village of Lacourt the granodiorite has undergone a strong alteration. The rocks have a different look although they are still homogeneous. The most remarkable feature, visible in handspecimen, is the occurrence of chlorite instead of biotite. Microscopically it appeared that the granodiorite has changed to a considerable extent and now it consists mainly of albite, chlorite and some microcline. Most of the quartz has disappeared. This process of albitization and chloritization must be due to a lowgrade metamorphism with introduction of sodium. A similar process has been described for the metamorphic and intrusive rocks of the Trois Seigneurs massif by Allaart (1958).

The Lacourt granodiorite has a rather peculiar shape due to the fact that in its center a large body of quartz-diorite belonging to the migmatite series occurs. The contact between both rock types is sharp and there is no transition between the two. Apparently the biotite-granodiorite is in intrusive contact with the quartz-diorite and consequently of later age. Since this body of quartz-diorite is now in a structurally much higher position than comparable quartz-diorites farther east, this body has apparently been pushed up together with, or perhaps by the intrusive granodiorite. The quartz-diorite itself is in all respects comparable to those farther east in the Arize massif and in the Trois Seigneurs massif. It contains the same minerals and the same structures. Signs of contact metamorphism near the boundary with the biotite-granodiorite have not been found.

The contact aureole in phyllites and mica-schists is several hundreds of metres wide and consists mainly of spotted slates and hornfelses in the phyllites and of micagranulites in the mica-schists. The phyllites close to the contact are transformed into andalusite-cordierite hornfelses; farther away from the contact spotted slates occur. The hornfelses show an unoriented texture whereby the original slaty cleavage has disappeared almost completely. The matrix consists of an intergrowth of quartz, biotite and muscovite in which small porphyroblasts of andalusite and cordierite are set. Usually both aluminium-silicates are more or less strongly altered to sericite and muscovite; biotite may be chloritized. In the spotted slates the original cleavage is still a pronounced feature; the spots, now consisting of sericite aggregates, but originally probably of andalusite or cordierite are the reuslt of contact metamorphism.

In the mica-schists contact metamorphism has resulted in the formation of unoriented micaceous rocks. Close to the contact they contain sillimanite and cordierite; all traces of the original schistosity have gone. Farther away from the boundary with the granodiorite the schistosity becomes more conspicuous until outside the aureole normal mica-schists occur.

The granodiorite of Bordes-sur-Lez

The granodiorite of Bordes-sur-Lez shows the same characteristics as those of Oust and Lacourt. It is a biotite-granodiorite with typical igneous textures and sometimes hornblende-bearing. Deuteric alteration of the primary minerals is very common. Most of the feldspar is sericitized and biotite is chloritized. Contact rocks close to the granodiorite show a highgrade assemblage. In the calcareous Devonian bytownite-biotite-garnet hornfelses and grossularite-humite-diopside marbles have been found, and in the Silurian chiastolite-hornfelses. S-W of Bordes-sur-Lez lower grade hornfelses probably in Devonian rocks occur. They are greenish looking, dense aphanitic rocks consisting mainly of quartz, chlorite, sericite and clinozoisite.

The Riberot granodiorite

The Riberot granodiorite, completely enclosed by Devonian slates and limestones, is again an intrusive biotite-granodiorite similar to the Lacourt, Oust and Bordes stocks. Hornblende-bearing granodiorites are not uncommon, especially near limestone contacts probably as a result from contamination. The two small granodiorite occurrences north of the main body are also hornblende bearing. In the borderzone a magmatic breccia occurs, consisting of biotite-rich clots with a few xenoliths of the enclosing sediments. The amount of xenoliths and autoliths becomes less toward the interior of the stock and at about 100 m from the contact they disappear almost completely. In the western part of the body a large raft of Silurian black slates occurs. This part is also characterized by a slightly foliated texture of the granodiorite in E—W direction; elsewhere the granodiorite is directionless.

Except for a few small examples, dykes are absent in the granodiorite. Locally patches of a leucocratic granite with radially shaped tourmaline crystals have been observed.

The contact aureole is a few hundred metres wide and consists of dark coloured, strongly indurated hornfelses in the slates, and garnetiferous marbles in the calcareous rocks. The hornfelses consists of quartz, biotite, garnet and clinozoisite. Spotted slates have not been found. The marbles contain besides calcite or dolomite abundant grossularite; further clinozoisite, bluish-green hornblende and scapolite have been found. One specimen is a phlogopite-tremolite rock. In most of the hornfelses and marbles only few traces of the original cleavage remain.

Dykes

A dyke belt running in E—W direction is one of the salient features of sheet 1 and 2. This belt, similar to the one in the Valle de Arán (see sheet 4) crosses the Pique river near Guran and can be followed due east over Argut, Melles, Pic de Paragrano to Lascoux in the Lez valley. A large number of occurrences is shown on the map but many more certainly are present in this zone. The dykes are to be found in rocks of Devonian, Silurian and Cambro-Ordovician age, but there seems to be a slight preference for the Silurian. Many of the dykes are intruded parallel to the cleavage or they may cut across. The majority of the dykes themselves does not show the presence of cleavage. These properties suffice to conclude that they are emplaced after the main Hercynian folding.

As has been suggested previously they might be connected with the intrusive biotite-granodiorites. The dykes are, however not more abundant near the batholiths; to the contrary they seem to avoid the granodiorites and hence this connection is only based on their intrusive character, age and composition.

It should be remarked that some of these dykes at the Pic de Paragrano N. E. of Melles have been described by Raguin (1946) as vestiges of volcanic activity during the Ordovician period and that they actually are lava flows. However their uncleaved and unfolded nature, similar composition as the other dykes and their occurrence in this belt are certainly contradictory to Raguin's opinion and there can be little doubt as to their late Hercynian age.

Most of the dykes are dense white or greenish rocks, often with a clear porphyritic texture and showing brown specks of altered pyrite. Their thickness is usually not more than a few metres but occasionally they may be up to 20—30 m thick as for instance at the Pic de Paragrano. In the Val de Burat a larger mass of a finegrained muscovite-granite occurs. Most of the dykes show porphyritic textures with phenocrysts of quartz, sodic plagioclase, potash feldspar and biotite. Rocks with only quartz or quartz and plagioclase phenocrysts are most abundant and can be classified as quartz-diorite porphyrites. Some dykes do not show phenocrysts and are aplites. All rocks are strongly altered; feldspars are sericitized, biotite is chloritized. Sometimes this alteration is so strong so as to make positive identification difficult or even impossible.

Contact metamorphism along the dykes is only slight or completely absent. Spotted slates and some hornfelses occur near the granite in the Burat valley.

TRIASSIC-JURASSIC-LOWER CRETACEOUS

The map sheets are primarily concerned with the Paleozoic rocks, the post-Hercynian cover is only represented in very summary way with only a subdivision in: *Trias,* subdivided to some extent in the Arize massif, *Lower-Mesozoic* containing the Jurassic-Lower Cretaceous sequence and finally the *Upper Cretaceous-Tertiary* rocks. This very limited representation of the younger rocks is due to the fact that we abstained purposedly from mapping them on request of our French colleague in Toulouse except where they were in direct contact with the Paleozoic.

Triassic

The psammitic red rock unconformable cover of the Paleozoic rocks is often referred to as Permo-Triassic, but as fossil evidence for the presence of Permian is missing, except on the southern Pyrenean border (Pallaresa valley) where it is unconformably overlain by the red-rock sequence and apparently forms the top of the Stephanian sequence, we prefer to regard the red rock sequence provisionally as Triassic only.

The Triassic west and east of the Garonne river along the N. Pyrenean fault, on sheet 1, consists only of conglomerates, sandstones and mudstones and transitions from one to the other, but in the sequence round the Arize massif (Keizer, 1954) on sheet 2 one can recognize a basal red rock sequence overlain by limestone (Muschelkalk) and marls and shales of the Keuper with large andesite masses.

The absence of Muschelkalk and Keuper along the north Pyrenean fault zone may be due to non deposition, but proofs are lacking because the northern boundary of this Triasic band is always the fault zone.

The sections are very variable and in the Garonne region the conglomerates, consisting almost exclusively of white quartz pebbles, often do not occur at the base of the formation but some 30 or 40 m above it on top of micaceous sandstones and mudstones. A typical section from south of Marignac, between the Pique and Garonne rivers is given by fig. 6.

In the Arize massif (Keizer 1954) the basal red Triassic starts in general with a conglomerate but contains higher up in the sequence numerous limestone breccia horizons alternating with shales or sandstones (fig. 7). The conglomerates and sandstones are often very ferruginous and have even given rise to hematite exploitation. On top of the red series occur occasionally small basaltic lava flows.

On top of the red psammitic series occurs a 50 m thick blue dolomite or limestone often underlain by a cavernous limestone with siliceous limestone (fig. 7) which is referred to as Muschelkalk although fossils are lacking.

The Triassic series end with well stratified grayish yellow marls which are regarded as belonging to the Keuper, containing large masses, badly exposed, of an andesite consisting of plagioclase and clinopyroxene, with epidote and chlorite as alteration products. This lava flow is in the French literature referred to as ophite. Lacroix already distinguished the volcanic ophites from the intrusive ones. The former are clearly of Triassic age, occurring as flows in the Keuper; the latter, however, are younger and intruded along the north Pyrenean fault in Cretaceous time.

Jurassic-Lower-Cretaceous

As we have not studied the Mesozoic strata, we will refer the reader for general purposes to Casteras 1933 and Dubar, 1925 on this subject.

The succession of Infra Lias and Lower to Upper Lias consists of a marine limestone facies, which follows on the evaporite facies of the Upper Trias. At the start of this change to pure marine conditions we still find bituminous pelites and marls, but in the Lower Lias gray dolomites and pure limestones predominate which continue somewhat more marly to the top of the Lias.

The Dogger is represented by black dolomites with frequent limestone intercalations.

It was formerly supposed that near the end of the Jurassic a period of emersion occurred, which was responsible for the absence of the uppermost Jurassic and lowest Cretaceous. The black dolomites were attributed to the Bajocian and Bathonian, and the overlying massive limestone to the Aptian. This long emersion was thought to be also responsible for the bauxite deposits east of Foix. A detailed microfacies study of this series recently has proven that for instance in a section near the Garonne valley just north of the Barousse massif (from Thèbe to Troubat) the whole series from the Bajocian upwards into the Neocomian is complete (Casteras et al 1957). Further east an emersion occurred only at the end of the Portlandian and the bauxite deposits are of Neocomian, Pre-Aptian age.

To call this Pre-Aptian emersion an orogenic phase is certainly going to far, but it does represent the first announcement of the Alpine orogenesis, followed somewhat later by a pre-Cenomanian tectonic phase.

The Aptian consists of a thick series of massif limestone of Urgonian facies, which is followed in the Albian by marls and pelites. It is principally these Urgonian limestones and Albian pelites which have been marmorized and metamorphosed in the north Pyrenean fault zone (Ravier, 1957) and contain the basic rock intrusions.

LHERZOLITES AND OPHITES

Besides the obviously Triassic ophite (andesite) occurring in the NW part of the Arize massif, numerous other ophitic rocks occur on sheet 1 and 2. Their

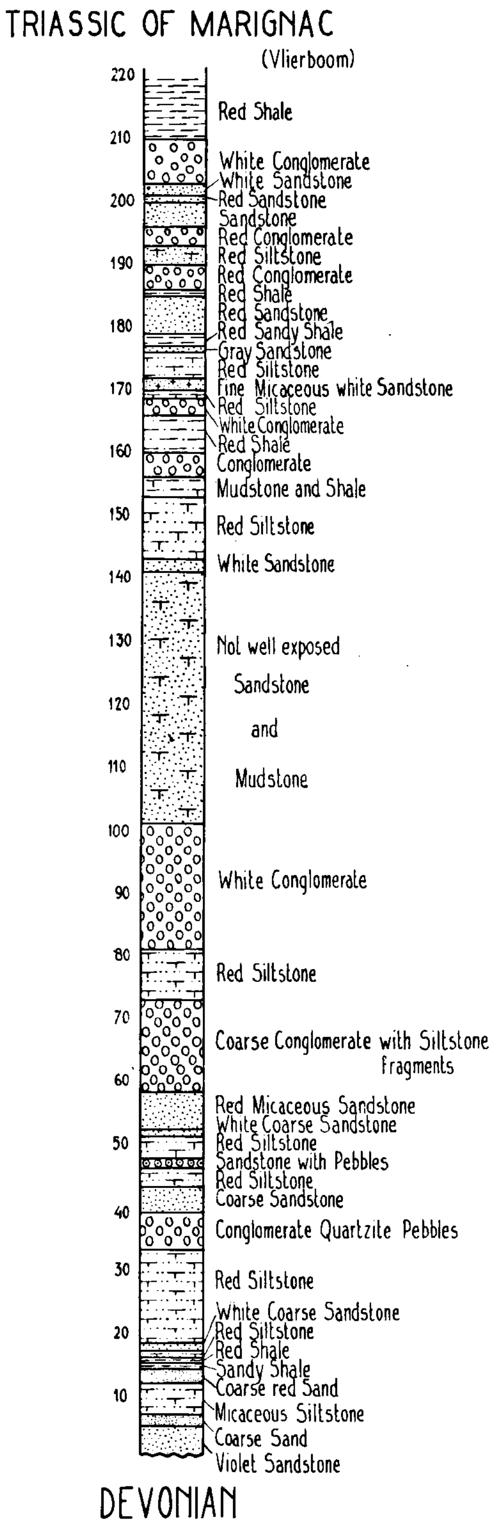

Fig. 6. Section of Triassic south of Marignac

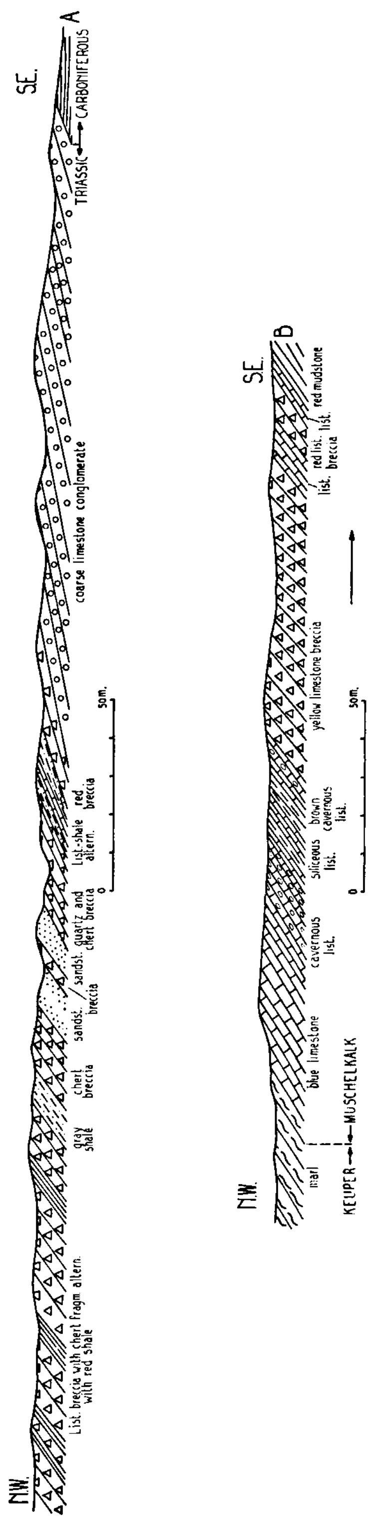

Fig. 7. Two sections of Triassic in Arize Massif;
A. along line Rimont–Cuilleré; after Keizer, 1953. B. near Rimont; after Keizer, 1953.

geologic setting is fundamentally different from that in the Arize massif. In several previous publications we have defended the view that most of these ophites are intruded along the north Pyrenean fault zone and must be of approximately the same age as the lherzolites, that is post-Albian and pre-Cenomanian. This opinion, which was also held by the early French geologists, has been changed by later French geologists and it is now believed that all ophites, irrespective of their geologic situation are of Triassic age. Many of the ophites along the north Pyrenean fault zone, however, are clearly in contact with Jurassic and Lower Cretaceous rocks, especially those on sheet 1 and 2 and they show exactly the same relations to their surroundings as the lherzolites. In a recent publication Ravier (1957) admits that many of the ophites on sheet 1 and 2 must have been intruded along the north Pyrenean fault zone. Nevertheless he maintains that the ophites were emplaced during the Triassic period and the lherzolites in Cretaceous time. There seems to be no foundation for his conclusion which must be based mainly on historic considerations.

Ophites also occur along faults branching into the Paleozoic for example south of the Bordes granodiorite and in the Salat valley near Col de la Serre du Cot. In the latter occurrence Zandvliet (1960) was able to prove the Cretaceous age of this ophite by the occurrence of a large block of metamorphic Urgonian limestone on this intrusion near the fault. The surrounding Devonian also shows thermal metamorphism, albitization and the same is true for the Etruc ophite.

The ophites consist of plagioclase (andesine to labradorite) and clinopyroxene with ophitic texture. Albitization of the plagioclase and uralitization of the pyroxene are common.

The lherzolites are peridotites containing olivine and enstatite with minor bronzite, chrome-bearing diopside and picotite. Serpentinization is to be observed in most outcrops.

Mesozoic metamorphism

The metamorphism of the Mesozoic has recently been described by Ravier (1957) and for details concerning this matter we refer to his thesis.

This peculiar metamorphism is restricted to a zone immediately north of the axial zone and attacks almost exclusively Mesozoic, pre-Cenomanian rocks. The metamorphism occurs in the same zone as the lherzolites, but according to Ravier it is not a contact metamorphism caused by these ultrabasic rocks, but a regional metamorphism. Undoubtedly there must be a common cause for the occurrence of lherzolites and metamorphism but as long as the particular character of this transformation is badly understood, there is no reason to speculate on this common cause. Ravier distinguishes three degrees of metamorphism of which only degree I and II are found in rocks on sheet 1 and 2, for instance near Seix and Sentenac and in the zone Audressein-Illartein-Galey. Mesozoic rocks containing green hornblende have been found in the Bethmale valley and are only briefly mentioned by Ravier. According to this author green hornblende should be indicative of degree III.

The metamorphism itself is of a static type and the rocks usually show a completely unoriented texture. Scapolite (mizzonite) is one of the common and also characteristic minerals; further basic plagioclase, biotite, titanite and tourmaline have been found.

THE CENOMIAN

The Cenomanian, deposited unconformably on the Jurassic- and Urgonian-Aptian limestones and older rocks, has a peculiar facies development indicating that the northern border of the axial zone formed roughly the border of the Cenomanian basin. It has been described by Dalloni, 1938, Casteras, 1951, Wissink, 1956 and Souquet 1959.

Along the north Pyrenean fault line we find relative large outcrops in the Esbints valley south of Seix (Wissink, Souquet) and between Bordes sur Lez and Coucou (Dalloni, Casteras) and between Alos and Engomer and round Fougaron (Casteras), the latter two more or less in the continuation of the Oust basin (Casteras, 1933). The Alos-Engomer zone was originally mapped as Silurian, but has been proved to be of Cenomanian age. It consists mainly

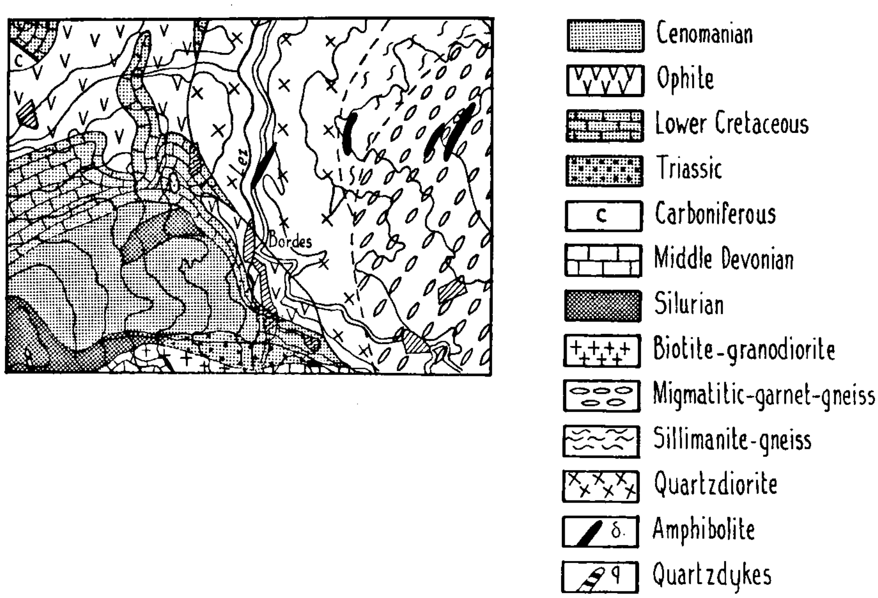

Fig. 8. Geological map of surroundings of Bordes-sur-Lez, showing extension of Cenomanian.

of pelites with numerous intercalations of arkoses and microbreccias and of numerous granitic boulders and blocs. The conglomerates, interstratified in the 1500 m thick band, are often polymict, sometimes monomict consisting exclusively of rocks of the Castillon massif. The blocks can reach 1 m^3 in dimension and consist of granitic material, Devonian or Urgo-Aptain limestone. Apparently they slid down in the mud and are directly derived from a coastal cliff.

The outcrop of the Esbints valley, found by Wissink, 1956, has been proved to be of Cenomanian age by Souquet, 1959 by its microfauna. It consists of limestone and polymict limestone breccias (Keuper, Lias, Jurassic, Urgonian), all rocks from its immediate surrounding.

The Cenomian band between the Bouigane massif and the axial zone consists of conglomerates, breccias, arkoses, and limestones with a Cenomanian fauna. Again there can be no doubt that the deposit is of coastal origin. Everywhere the basal beds of conglomerates are derived directly from the underlying beds changing with the change in the underlying rocks. The feldspars in the arkoses are also directly derived from the underlying granite, they are hardly rounded with the result that at a first glance the rock looks more like a weathered granite than an arkose.

Its extension is somewhat larger than shown on the coloured map (see fig. 8).

UPPER CRETACEOUS-TERTIARY

Sedimentation continued unbroken from the Cenomanian upwards, which gradually becomes less marine. The Danian is represented by a fresh water lithographic limestone, but the Lower Eocene is marine again, with an alveoline limestone in the Lower Lutetian. They are covered by thick conglomerates of presumably Upper Lutetian age, called the Palassou conglomerates. The Pyrenean phase of folding occurred before the deposition of these conglomerates, which are much better exposed on the southern border of the Pyrenees in the Pallaresa and Ribagorzana valleys and are called there the Pobla conglomerates. These are frankly discordant on anything from the Silurian upwards.

The continuation of sedimentation is of a Molasse facies in the northern marginal trough of the Pyrenees, in which the Miocene may be unconformable on the Oligocene again. The final upheaval of the whole Pyrenean Mountain chain occurred in stages after the Miocene as was proved by a lignite deposit in the central chain (de Sitter 1953).

The Alpine movement phases are:

1st phase	emergence Pre-Aptian
2nd phase	folding-faulting of north-Pyrenean fault Pre-Cenomanian
3rd phase	folding phase Pre-Upper Lutetian or Pre-Bartonian
4th phase	slight emergence, some tilting Pre-Miocene
5th phase	morphogenetic emergence Post-Miocene.

STRUCTURE

On sheets 1 and 2 of the map of the Central Pyrenees the following structural units are represented:

The axial zone
The north Pyrenean fault zone
The satellite massifs, Barousse massif
Bouigane massif
Castillon massif
Arize massif
Trois Seigneurs massif.

The relation between the satellite massifs and the axial zone is rather obscure, because the north Pyrenean fault zone has acted repeatedly and differently in various regions.

AXIAL ZONE

The width of the axial zone stretch on these two sheets is only about one fifth of the whole. Its large overall structure is here characterized by its consistent E—W or WNW—ESE strike with a dome in the Garonne region and a depression in the Estours region. The distance from the top of the dome to the bottom of the depression is some 30 km and the difference in height at these points of a particular stratigraphic horizon is roughly 3 km. The overall plunge of the axis is therefore roughly 5° only. Steeper plunges do occur of course in individual folds.

In describing the major structures of both sheets, a distinction has to be made between the Cambro-Ordovician on one hand and the Devonian-Carboniferous on the other. The Cambro-Ordovician of the axial zone, mainly represented on sheet 1, is a broad dome with essentially horizontal or flatlying structures and a steep north and south flank. These horizontal structures might at first sight be interpreted as nothing more than a simple doming with hardly any folding or deformation, as for instance suggested by the flatlying metalliferous limestone near May de Bulard on sheet 2. Closer investigation as has been carried out by D. Boschma along the Garonne river, revealed, among other things, that the flatlying bedding is accompanied by a parallel slaty cleavage resulting from the crystallization of mainly sericite, and that minor, recumbent, asymetric folds, syngenetic with this cleavage occur in this area. For this major structure, closely resembling the metamorphic domes of the Pyrenees as far as structures are concerned, the name Garonne dome is proposed. Within this dome recrystallization locally reached a higher degree of metamorphism, viz. in the SW corner near Bosost. This mesozonal part of the Garonne dome is called the Bosost dome, but it is in fact a metamorphic dome; here the metamorphic isograds are domeshaped. Structurally it is a part of the much larger Garonne dome and the micaschists near Bosost display similar recumbent, asymmetric folds syngenetic with a schistosity as the phyllites in the remainder of the Garonne dome.

De Devonian and partly also the Carboniferous of the axial zone is folded in a different way. In these units steep folds with a near vertical, transverse axial plane cleavage have been generated. There can be no doubt that the slaty cleavage in these steep folds in the Devonian and the flatlying slaty cleavage and schistosity in the Cambro-Ordovician have been formed at the same time as demonstrated by parallelism of foldaxes in both units. Between the two types of structure the Silurian has acted as a shearing-off plane, being more or less horizontal at its contact with the Cambro-Ordovician and strongly folded and squeezed in the narrow anticlines of the Devonian (fig. 9). There can be no doubt that the very plastic nature of the Silurian slates predestined them as a detachment horizon. This behaviour has already been mentioned by Destombes in his description of the Pique section, although he did not recognize the different structure beneath and above it.

Such a structural difference between Cambro-Ordovician and Devonian as in the Garonne dome is rather unique in the Pyrenees. Farther south, as for example in the Pallaresa the Cambro-Ordovician shows the same steep cleavage folds as the Devonian, and although the Silurian is often strongly squeezed and locally reduced to zero, the folding above and beneath it is not so completely disharmonic as in the Garonne dome. Flatlying structures are, however the dominant feature of the regional metamorphic domes like the Aston-Hospitalet dome, but here the overlying low grade Cambro-Ordovician cover contains steep cleavage folds and the transition between the flatlying and steep structures is much more gradual, apparently due to the absence of a strongly incompetent layer. Although in the Pyrenees the transition between flatlying and steep structures lies usually somewhere around the biotite isograd, the Garonne dome is different by the fact that it contains the horizontal metamorphic structures but the grade is only epizonal and not mesozonal as usual. The cause of this difference remains thus far unknown to us, but there can be little doubt, that the whole Garonne dome is underlain by a gneiss dome like the Aston and Canigou massifs. As such this gneiss dome reached probably higher in the stratigraphic sequence than any other dome in the Pyrenees as also witnessed by the fact that near Bosost even an important portion of the Devonian participated in mesozonal (andalusite-zone) metamorphism. From the Garonne eastwards, the situation of the gneiss domes becomes gradually deeper; the Aston-Hospitalet dome occurs still in the upper portion of the Cambro-Ordovician; the Canigou dome reaches only to the Canaveilles series, probably belonging to the Cambrian.

These dome-structures, including the Garonne dome, belong clearly to the infrastructure of the Pyrenees: the steep Devonian and Carboniferous folds to the suprastructure.

The whole zone of Devonian west and east of the Garonne dome consists of a varying number of anticlines and synclines with an amplitude from 1 to 4 km, often accompanied by longitudinal upthrusts. In the anticlinal cores we find Silurian slates, in the synclines Devonian slates and limestones. Each of the km-wide structures shows 100—500 m wide subsidiary folds and in outcrops minor folds of 1—10 m size and smaller can often be observed. Although all

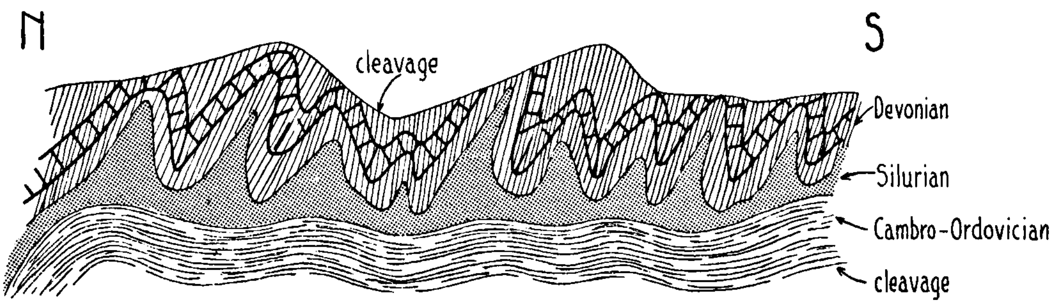

Fig. 9. Diagrammatic section through northern part of Garonne dome, showing horizontal cleavage in Cambro-Ordovician, and steep cleavage in Devonian. Influence of refolding phases omitted.

are parallel to one another, and certainly many of these folds belong to one major folding phase, there can be no doubt that especially some of the minor folds belong to a later phase of refolding. The kilometre-wide folds west of the Riberot valley are together superimposed on the gentle north flank of the Garonne dome which is situated between the upper Valle de Arán synclinal region and the northern boundary of the axial zone. This part of the Garonne dome has been called central anticline by Kleinsmiede(1960) and shows a particular good development of the Caradoc limestone, which has been described repeatedly because it contains a lead-zinc mineralization exploited by the Bocard and adjacent mines on the Spanish side of the frontier (Liat mines). Durand and Raguin (1943) described the general structure, Destombes (1958) published about it, Visvanath (1959) remapped the region in 1953—55, Kleinsmiede (1960) incorporated our own survey which dated from 1950—52 on the Valle de Arán sheet and gave a set of cross sections, to which we refer the reader. The most striking feature of these sections is the fact that both flanks have been thrust up against the central portion. Such steep upthrusts represent probably a compression later than the folding and since the thrusts in the northern anticlines crossing the Riberot, Orle and Lez rivers have the same character, they probably belong to the same late thrusting phase. Because the thrustplane of the Couflens anticline again is of the same character, and this one is proven to belong to the Cretaceous phase by the occurrence of an ophite mass and a bloc of Cretaceous limestone in the faultzone, the other upthrusts are apparently also of Alpine age.

The details of the 100—500 m wide folds in the Devonian are not very well known in this region, much less than those described by Zandvliet (1960) from the region south and east of Couflens. The strongly wooded slopes of the rivers prevent accurate mapping of the individual limestone beds which cannot be followed for longer distances on the aerial photographs either. The folds in sections 2, 3 and 4 are therefore more or less approximative and sometimes as in section 2 and 3a conjectural. The same is true for the folding pattern in the Bouigane massif (sections 3 and 4).

Although initially the cleavage in the Garonne dome was flatlying, this is no longer everywhere the case, as a survey by D. Boschma has shown. This is due to later, but still Hercynian, refolding phases. Two main directions of refolding have been found, an older one in NW—SE direction and a younger one again in E—W direction. Both phases correspond to those described by the second author (Zwart 1960) from the Aston-Hospitalet massif. In the Garonne dome both phases of refolding are always accompanied by a new crenulation (= strain-slip) cleavage with steep attitude. Especially the E—W phase is important in the Garonne dome and is responsible for the presence of folds of at least several hundred metres size, accompanied by numerous minor and micro-folds. In many of these folds the originally horizontal cleavage has acquired a subvertical attitude. Still later shear joints and knickzones may deform all earlier structures.

In the Devonian outside the Garonne dome the same phases of refolding have been recognized.

It is still unknown whether the Cambro-Ordovician of the Arize massif belongs to the horizontal or the steep structures. A clear disharmonic behaviour of the Silurian has not been recognized there, but more detailed work is needed to solve this problem. The difficulty arises from the fact that the late phases of refolding have always affected the cleavage or schistosity, so that the mere measuring of dip of the cleavage in a few outcrops does not give a definite clue about its original position. Enough is known, however, to state that both, the NW and the E—W phase of refolding occur in this area, as usual accompanied by a secondary crenulation cleavage.

Apart from the main folding phase, an older phase can locally be recognized, in particular in the Upper Devonian-Carboniferous sequence of the Estours river.

Although in the largest part of the area covered by sheet 1 and 2 the folds show an axial plane cleavage in E—W direction, deviations of these trends have been observed in the Upper Devonian-Carboniferous of the Salat-Estours valleys. As can be seen on the map, sheet 1, the Carboniferous synclines do not display such a regular E—W direction as most folds of the older Paleozoic. Besides an E—W direction, also a distinct NE—SW trend seems to be present and both directions apparently interfere.

Especially well displayed are these relations in the Estours quarry in Upper Devonian limestones. Here a rather large fold with an axial plane striking N 30° E and dipping approximately 60° to the SE, and an axial plunge of 10° to the SW, is cut by a cleavage in a different direction. The cleavage dips ± 40° NNE and strikes E—W. Since the cleavage itself is undeformed and cuts obliquely through the fold, the latter must be older than the cleavage. There is little doubt that the cleavage belongs to the main phases of the Hercynian folding, so that the existence of a pre-main folding must be assumed. It seems probable that in the Estours region pre-cleavage folds in NE—SW direction are deformed by the cleavage of the main folding, roughly with E—W direction but locally divergent. Whether this divergence is due to later folding has not yet been established. Similar relations exist in the southern part of the axial zone but in its central portion most of the folds are parallel to the cleavage and the existence of an early phase of folding is difficult to establish.

A further characteristic of the Upper Devonian limestones are the stretched nodules, which now form elongate spindleshaped bodies, often many times longer than thick. Obviously these elongate structures must have formed by strong deformation contemporaneous with cleavage folding, which is corroborated by the fact that they are parallel throughout the entire fold. The long axis of these spindles, forming a distinct lineation, plunges within the cleavage plane towards the SE. Also elsewhere in the area steeply plunging stretched nodules have been observed. It is likely that the long axis of these nodules follows the intersection of bedding and cleavage and since both make an appreciable angle, these elongated nodules may have a varying position throughout this area.

Indications of this pre-main folding phase can also be deduced from the abnormal strike of some of the sandstones in the Carboniferous outcrops south of Col de Menthe.

The following table gives a summary of the various phases of the Hercynian folding

	pre-main phase	main phase	1st refolding	2nd refolding
Nature of folding	concentric no cleavage	cleavage- and shearfolding formation of Garonne dome and folds in Devonian wit slaty cleavage	folding of slaty cleavage, development of 1st crenulation cleavage	folding of slaty cleavage, development of 2nd crenulation cleavage
Direction	ENE—WSW	E—W	NW—SE	E—W

THE SATELLITE MASSIFS

The Barousse massif is, as far as it is represented on sheet 1 and except its core of metamorphic rocks, of very simple structure. It is half a dome, cut off on its southern boundary by the north Pyrenean fault. In its core metamorphic rocks dip north and north-east, and they are covered by slightly metamorphic Ordovician, non metamorphic Silurian and Devonian and a complete Mesozoic series starting with the Triassic.

The Bouigane massif is both from a structural and a stratigraphical point of view more a part of the axial zone than a satellite massif, but as it is undoubtedly separated from the axial zone by a fault zone and a narrow stretch of Cretaceous rocks, it must be regarded as one of the satellite massifs. Its structure is the direct continuation of Carboniferous-Devonian area east of St. Béat, south of the Col de Menthe on its west side, and of the Les Bordes granite-Devonian mass on its eastern side. It consists mainly of Carboniferous shales with on its southern border an overturned anticline with Upper Devonian and a narrow zone of

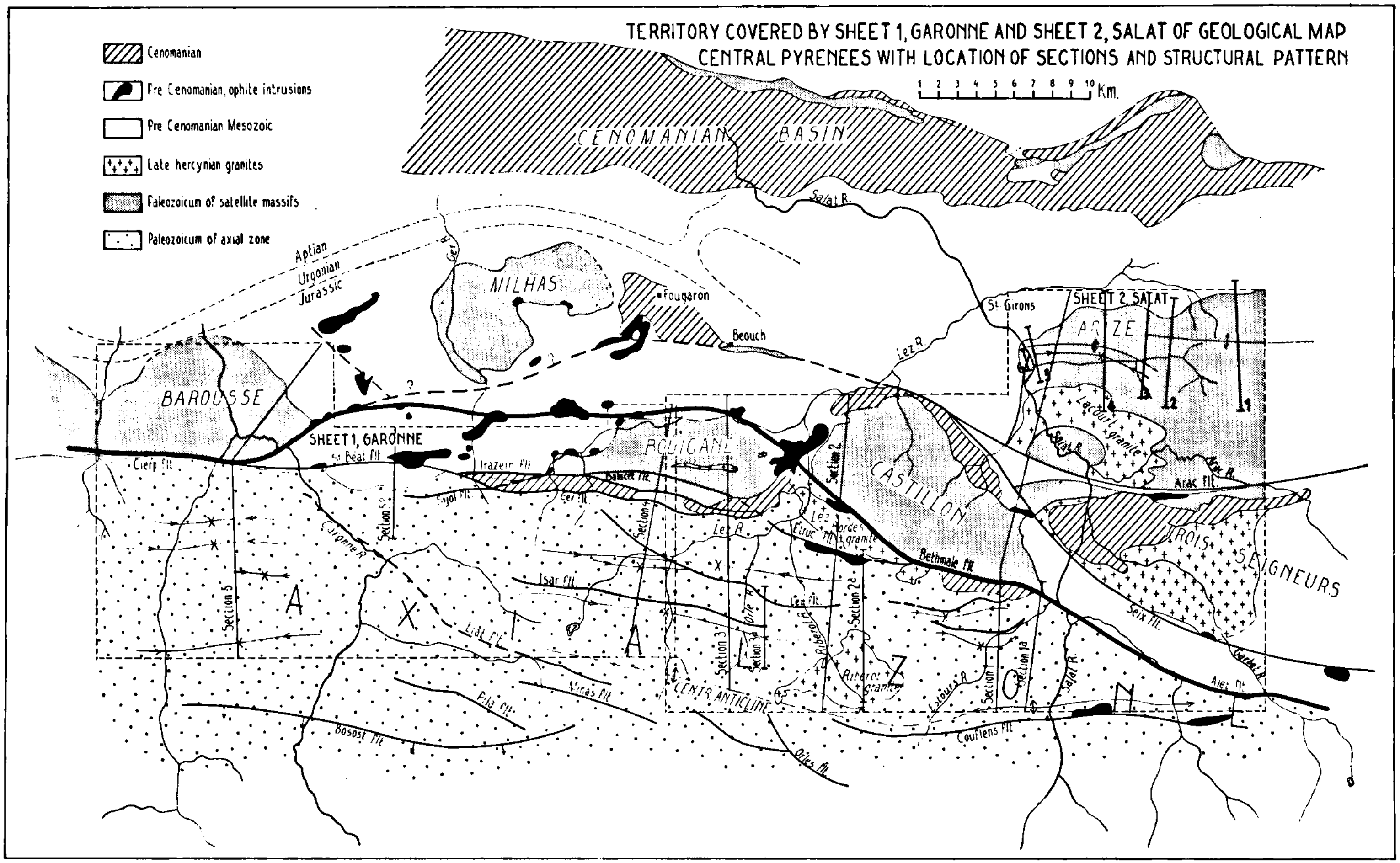

Fig. 10. Structural map of the Northern Pyrenees between Garonne and Salat rivers.

Silurian separated from the Devonian by a steep, slightly southdipping fault. This fault, the Balacet fault (fig. 10) can be followed westwards, where it brings Carboniferous in touch with the Silurian band and further west with a jump of 6 km in the axial zone south of Col de Menthe, where it, as the Sijol fault, separates again Silurian and then Devonian from the Carboniferous.

The Balacet fault followed eastwards is cut off by the unconformable cover of the Cenomanian. Either this fault or the branch of the N. Pyrenean fault just south of it reappears on the right bank of the Lez river as the Etruc fault along which a long intrusion of basic rocks occurs. This correlation of tectonic features from the Bouigane massif with those of the axial zone is accentuated by the occurrence of granite intrusions in the Bouigane massif similar to that of the Les Bordes granite and this proves that the N. Pyrenean fault from the Lez river westward to the Ger river is not such an important fault line, as far as its throw is concerned.

The Castillon massif is simply one block of the basal gneiss series, the highest grade of metamorphic rocks we know in the Pyrenees. The only outcrop of sedimentary rocks is a small patch in the north near Loutrein-Astien, which is supposed to be of Carboniferous age. It is undoubtedly separated from the gneiss by a fault, which can not be ascertained in the field except by the occurrence of a small block of Lower Cretaceous limestone on the supposed fault line. To the south the Castillon massif is bounded by the main branch of the N. Pyrenean fault to the north-west and north-east it is surrounded by Cenomanian strata mostly (Casteras 1951).

The Arize massif occupies the north-eastern corner of sheet 2. Keizer (1954) described the whole Arize massif and fig. 11, gives a reproduction of some of his sections located on our map. The rather asymmetric anticline with a Devonian core in section 1 (fig. 11) continues westwards, even becoming slightly overturned in the Carboniferous in section 2. North of the Lacourt intrusive granodiorite mass an extra anticline and syncline develop with an axial plane fault in the anticline. It has been suggestted that this structure is due to the pressure of the intrusive mass (de Sitter, 1954). Towards the west the Devonian anticline is cut off by a fault, which continues southwards cutting off the Devonian and Silurian-Ordovician of the central part of the Arize massif, and probably even the Lacourt granodiorite mass, bringing Carboniferous strata in a faultcontact with all these older rocks.

This narrow N—S striking Carboniferous band is at its turn truncated by the Trias and further south by the Lower Mesozoic. There can be little doubt that this north-south running fault is at least partly of Alpine origin.

In the broad stretch of Ordovician strata no particular structures have been mapped by lack of recognizable key horizons. The southernmost band of the Arize massif is formed by micaschists and gneisses which at their turn are cut off by the branch of the N. Pyrenean fault running between the Arize and Trois Seigneurs massifs.

The Trois Seigneurs massif, of which the largest and most interesting portion appears and has been described on sheet 3, penetrates with a triangle on sheet 2. It consists largely of the intrusive mass of the Oust granodiorite covered for a large part by the Cenomanian Oust basin (Casteras, 1933). Only on its northern border appear some Silurian and Carboniferous strata. No doubt its supposedly Carboniferous western point is separated by a fault from the granite, which is nowhere exposed however, neither is its boundary with the small most western gneiss triangle exposed. It could very well be that this latter triangle really

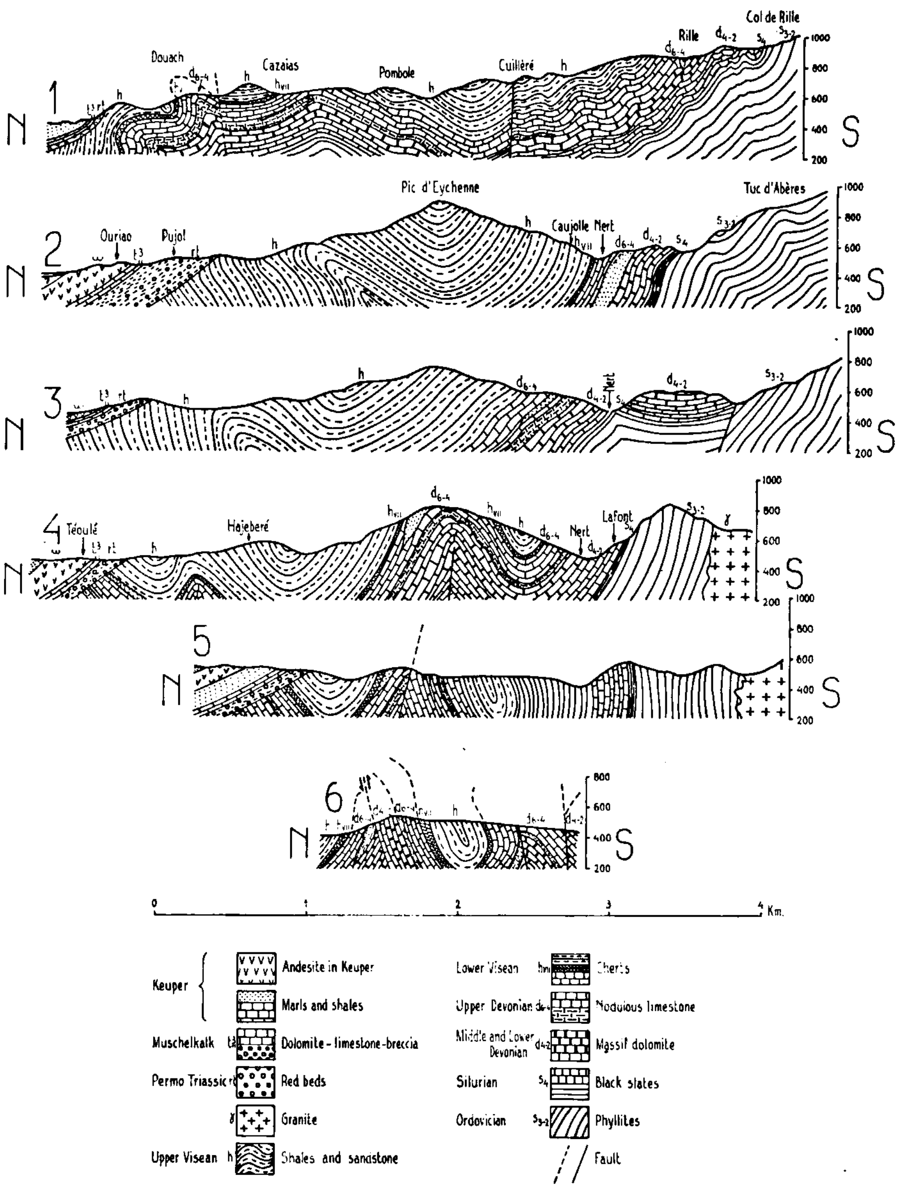

Fig. 11. Six cross sections through the western portion of the Arize massif; after Keizer, 1953.

belongs to the Arize massif. The Carboniferous continues eastwards in a very narrow band, down faulted between the north-Pyrenean faults between the Arize and Trois Seigneurs massifs. This faultzone is here accompanied by small cretaceous ophite masses (i. e. the Aleu mass).

THE NORTH PYRENEAN FAULTZONE

In a small note (de Sitter, 1954) the complex character of the north Pyrenean faultzone has already been emphasized. In the Mesozoic-Tertiary sequence two Alpine phases can be distinguished, a pre-Cenomanian, Austrian, phase and a Pyrenean (late Eocene) phase. In the Hercynian orogeny several phases occurred, but they can not be dated except the Asturian (pre-Stephanian perhaps pre-Upp. Westphalian) phase and probably an even later but pre-Triassic faulting phase (de Sitter 1954) in which the north Pyrenean fault system was active already.

The most important fault line between the axial zone and the satellite massifs has been drawn as a double line on fig. 12. If the Bouigane massif is regarded as a portion of the axial zone for reason mentioned before all the satellite massifs north of this line, Barousse, Milhas, Castillon and Trois Seigneurs consist mostly of metamorphic rocks separated by a large fault from the non-metamorphic Upper Paleozoic of the axial zone. This fault line makes an arc, convex to the north, an arc which is roughly repeated further north by the outcrops of Jurassic/Urgonian limestone/Aptien shales (see tectonic sketch map, fig. 12) but not by the Cenomanian. The great Cenomanian belt runs straight, roughly parallel to the Plantaurel. This straight belt of folds consists of Upper Cretaceous and Eocene and is therefore certainly a Pyrenean feature. The arc of the main fault line round the Bouigane massif and the Lower Mesozoic arc round the Milhas massif look as if they were originally of an older date, probably belonging to the Austrian phase.

The faultzone of the Irazein and Ger faults between the axial zone and the Bouigane massif necessarily is of the same age because the Cenomanian zone between the two faults has been strongly compressed.

This Cenomanian zone did not appear yet on Casteras' map of 1933, but was found later by Dalloni, 1938, reaffirmed by Casteras, 1951, as well as the Cenomanian cover round the Castillon massif (Casteras 1949, Raguin, Casteras, Fontan 1950) and the Cenomanian of the Esbints valley between the Castillon massif and the axial zone (Wissink 1956, Souquet 1959). Together with the Oust- and the Fougaron basin they show how strongly the Cenomanian coastal basins were influenced by the N. Pyrenean fault movements.

The only arc structure which is not accentuated by the Cenomanian basins is the one north of the Milhas and Barousse massifs, recognizable on the map by the Jurassic-Urgonian outcrops. If we assume that this arc is the oldest one, linking up with the Seix fault or better still with the Arac fault, the development of the north-Pyrenean fault system would look something like fig. 12. First arc 1, then arc 2 were formed and finally the straight fault line 3 and the bridging faults between arc 2 and 1 numbered 4.

The satellite massifs Barousse, Milhas, Castillon and Trois Seigneurs would belong to the belt between arc 1 and 2, the Arize-St. Barthélemy massifs outside and the Bouigane massif inside this double arc. All these fault lines were accompanied by tilting of the blocks between them and all of them were formed before the Cenomanian. The argument that the wedging out southwards of the

Triassic strata round the satellite massifs of Arize and Trois Seigneurs proves that some of their tilting was late Hercynian is also true for the Barousse massif. The arcs 1 and 2 would then be pre-Triassic and the straight fault lines of the Ger and Irazein faults could have been initiated only in the Austrian phase.

A thick fault breccia on the north Pyrenean fault occurs between the Permo-Triassic and the Urgonian limestone near Cierp. It contains fragments of Paleozoic slates and of biotite granodiorites and therefore postdates the Hercynian folding and intrusion. This breccia has been known for a long time and was called "magma de Cierp" by De Leymerie.

All the faults are accompanied by ophite intrusions in the Paleozoic and Mesozoic rocks older than Cenomanian and the peculiar metamorphism of these rocks has lately been treated very extensively by Ravier, 1954 and 1957. The original conclusion of Casteras that because the Albien limestones and pelites are strongly affected by this metamorphism but the Cenomanian rocks not, the intrusion and metamorphism linked to the fault system must be pre-Cenomanian, has been confirmed by Ravier. Apparently Ravier did not consider the basic rock intrusion along the Couflens fault and the Etruc fault as belonging to the same phase and did not visit them, neither is the intrusion on the Bethmale

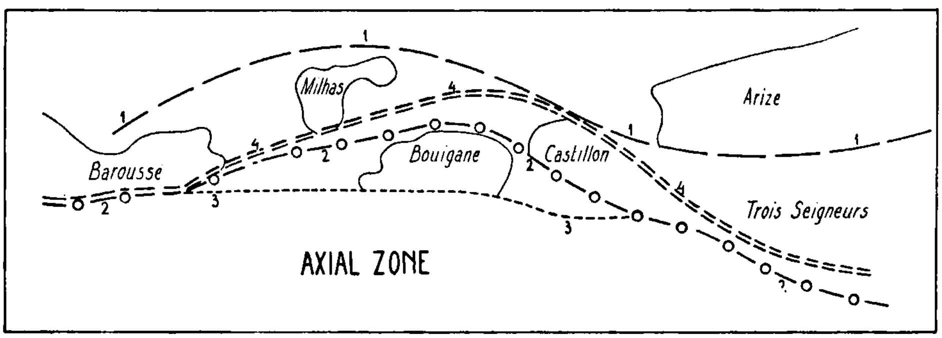

Fig. 12. Successive stages in the development of the North-Pyrenean fault zone.

fault, surrounded by highly metamorphic Albian limestone (hornblende bearing) described in this thesis.

One very peculiar feature rests to be mentioned. Along the whole Cenomanian strip between the Bouigane massif and the axial zone small slabs of red Triassic rocks are lying on the Cretaceous. For some of these outcrops, where the vegetation prohibits a detailed view, a piercing through might be proposed, but other ones, for instance those near Balacet show that undoubtedly the Triassic shales lie on the Cretaceous. In some of these outcrops the Triassic is associated with any other kind of rock, Paleozoic or younger. There can be no doubt that they represent klippes of some post Cretaceous gliding movement, later even than the strong folding of the Cenomanian itself.

It seems reasonable to suppose that the klippes represent a gliding movement northwards of the Triassic cover of the axial zone over its northern border. Some Triassic is found also on the Carboniferous of the Bouigane massif, but they belong probably to the normal not displaced cover, in particular because they occur frequently (more than is indicated on the map) just south of the granite ridges.

MORPHOLOGY

The physiographic features of the area covered by sheets 1 and 2 has never been studied as a whole and thoroughly, neither by us nor by our french colleagues. Chevalier, 1954, gave a review of the glacial influence on the surroundings of the Salat and Lez valleys; Sermet, 1950 gave a general review of axial zone, but neither of them went much into details.

The portion of the axial zone on our maps is narrow, comprised between the Upper Garonne river in the Valle de Arán and the Lez river and therefore little has been preserved of the wellknown planation surfaces round 2000 m and 2400 m altitude. For the same reason the glaciers have remained small and their erosive force almost negligable.

On sheet 2 the principal branch of the N. Pyrenean fault line, separating the axial zone from the external zone is topographically well expressed by the valleys of the Alet, Esbints, Bethmale and Bouigane rivers.

On sheet 1 it is surprising to see how independent the course of the Garonne river is of this most prominent structural feature, it crosses the fault near St. Béat, breaks through the wall of marmorized limestone in a narrow gorge and continues its course cutting right across the gneisses of the Barousse massif. The same is true for the Pique river.

A similar independence of the large structural features is exhibited by the Salat river, it crosses both branches of the N. Pyrenean fault, north of the Axial zone, enters the Trois Seigneurs massif, crosses the Arac fault and cuts through the Lacourt granite of the Arize massif.

The only structural unit which is morphologically well expressed is the Castillon massif, forming a dome both in the structural and in the physiographic sense.

This independency of the main river courses of the structural features is of course due to the longitudinal arching up of post Miocene planation surfaces in the post Alpine morphogenetic phase, the rivers running off the northern slope. Little has been preserved of these surfaces in our region. The ridge between the Pique and Garonne rivers south of our map still contains some flat surfaces and is of a rather uniform height of $\pm$ 2000 m, but further northwards the Burat valley comes between these two rivers and the ridges between them become lower and sharp.

On the ridges between the tributaries of the Lez and Salat rivers very little of the original 2000 m planation surface has been preserved. The valley slopes are very steep, the ridges are sharp. The extension of the latest glaciation can be reconstructed and as the small map of the upper Lez valley shows (fig. 13) they did not extend far into the valleys.

In the Riberot valley the end moraine is found just before its entrance into the Lez valley. But in this valley it can be proven that an older glaciation must have occupied the valleys much further down. First of all beautiful side morains are preserved in the side valleys, 200 m above the main valley bottom and secondly granite boulders have been found on the northern slope of the Lez valley above Sentein-Lascoux also 200 m above the valley. It is probable that this older glaciation reached as far as the gorge upstreams of Castillon. It is certain also that during that glaciation the Riberot glacier, charged with granite boulders derived from its beautifully preserved cirque in the Riberot granite, flowed over the ridge in the Etruc valley.

In these narrow valleys the postglacial erosion has destroyed the original

U-shape to a considerable extend in the lower reaches of the valleys although its incision is small, a feature common to all the central Pyrenees valleys. In the higher valleys the glacial shape is still admirably preserved.

A particular interesting feature are the caves in the Upper Ordovician limestone of the Upper Lez valley. In the region where this limestone is exposed

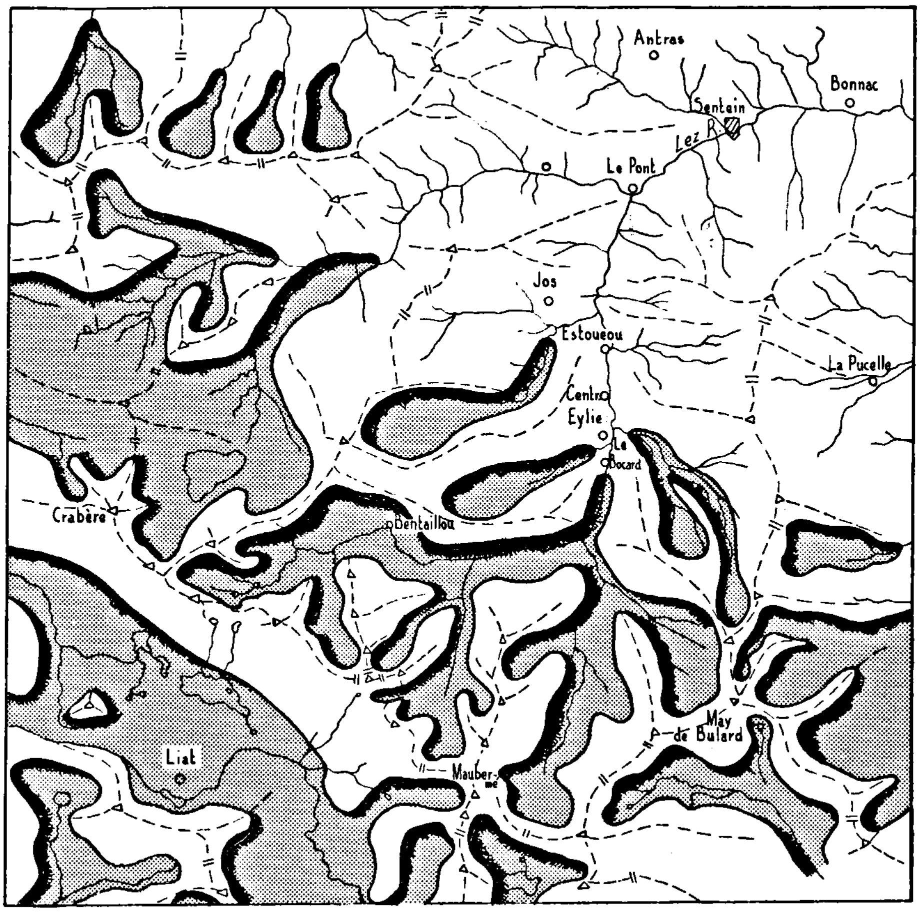

Fig. 13. Glacier extension in the Upper Lez valleys during the latest glaciation.

there has not been any post glacial erosion, all the water disappears into the limestone by means of very frequent sinkholes with diameters ranging from 1 to 10 meters. One of these underground water courses has been extensively surveyed from its sinkhole, the "Gouffre Martel" to its cave opening in the valley of Cigalère, 430 m lower. It consists of long corridors, large and high caves with well preserved stalactites and stalagmites, lakes and waterfalls.

ECONOMIC GEOLOGY

Except for a few quarries active exploitation of economic deposits on sheets 1 and 2 has ceased since the large lead-zinc mine of Bocard near Sentein was closed in 1955. Several lead-zinc mines existed in the area during the first half of this century but only those in the Val de Burat and near Sentein were of any importance. Further, phosphate near Cierp and manganese in the Arize massif have been worked. A few quarries mainly for ornamental stone and road metal are still in operation.

LEAD AND ZINC

Argentiferous lead and zinc ore have been exploited in the Val de Burat and in several mines south of Sentein, between de May de Bulard and the Tuc de Seneviès. The latter deposits have recently been described by Visvanath (1959) and we will follow his description. The following mines are mentioned: 1) Bocard (the largest one), 2) May de Bulard, 3) Port d'Orle (in Spain), 4) Port d'Urets, 5) Artignac, 6) Portillon d'Albe, 7) Uls, 8) Crabère, 9) Flouquet. Further a rather important mine occurred near the Etang Liat on the Spanish side of the high ridge. All other mines were small workings of no economic importance.

The following ore minerals have been identified near the Bocard mine: sphalerite, galena, pyrrhotine, pyrite, arsenopyrite, chalcopyrite and covelline. The stratigraphic distribution of the ore is in the infra-Caradoc phyllites, in the metalliferous limestone, in the Silurian black slates and in the Devonian limestone. Except for the metalliferous limestone the mineralization is very weak, so that all the mines occur in this limestone.

In the Bocard mine the lead content decreases with depth whereas zinc increases in this direction. In the Cigalère cavern Casteret has discovered stalagmites and stalactites covered with sphalerite. According to Visvanath this is due to solution and redeposition of the larger ore bodies and is a rather recent feature. The thickness of the veins varies from 1 cm up to 5 m and decreases with depth. The metalliferous limestone is often strongly mineralized near its upper boundary with the phyllites which seem to have acted as an impenetrable screen. On the other hand when no mineralization is found near the upper contact, the lower contact of the limestone may be strongly mineralized. The gangue mineral is mostly quartz, and formed from the beginning to the end of the mineralization. There is no doubt that these deposits are of epigenetic nature and of hydrothermal origin.

The mines in the Val de Burat, also producing lead and zinc are mainly of the same nature as those near Sentein. However, the mineralization did not take place in the metalliferous limestone, but in the Ordovician phyllites.

MANGANESE

Several manganese occurrences have been described in the Arize massif, of which the most important one, that of Las Cabesses, occurs near the eastern margin of sheet 2. Other occurrences are known under the name of Le Coch, Touron, and Crabious. All manganese deposits are to be found in the Upper Devonian "griotte" limestone close to the contact with the Carboniferous (Dinantian) shales. Not only in the Arize massif, also elsewhere in the Pyrenees and the Montagne Noire manganese deposits occur in the Upper Devonian nodular limestone. The ore is found in cavities in the limestones and can be divided in two zones, an upper oxidized and a lower zone with carbonates like dialogite and manganiferous calcite and with haussmannite. Further manganese black earth occurs in the same zone. It seems certain that the ore is of syngenetic origin since it is bound to the same stratigraphic horizon and also because manganiferous shales occur in the Carboniferous shales, of which the manganese content is thought to be derived from the underlying manganese deposits. Therefore the ore certainly antedates the Hercynian folding and also the intrusive granodiorites.

The most important deposit of Las Cabesses has yielded 460 000 tons of ore. The second best mine of Cazales only 18 000 tons. Both are since long closed down.

According to Fournié the following events have lead to these manganese deposits: deposition of Upper Devonian nodular limestone with little manganese; emergence during the Tournaisian with karstification, alteration and leaching with residual concentration of manganese in solution holes in the limestone; subsidence resulting in deposition of Visean shales.

PHOSPHATES

The phosphate nodules in the chert horizon at the base of the Carboniferous have been exploited for a short time near Cierp on sheet 1, and at a few places in the Arize massif on sheet 2. However the deposits are all rather small and of little economic value.

The origin of the phosphate nodules and the chert in which they occur remains enigmatic.

ORNAMENTAL STONE

Three rather large quarries in which ornamental stone is worked occur on sheet 1 and 2. Near Estours is a large quarry in the Upper Devonian nodular limestone, where large blocks are sawed through with wire saws. From the quarry these blocks are transported to Pont de la Taule where they are cut in large plates of about one inch thick and then used for various purposes in buildings.

Another quarry occurs near Balacet in the Cenomanian brecciose limestones. The same procedure is followed in this quarry as in Estours.

Near St. Béat a large quarry is in operation in the Urgo-Aptian limestone which locally is brecciated (the so-called "brèche romaine"). Also these quarries work with wire saws and the rock is used for building.

Several other smaller quarries on sheet 1 and 2 mainly in Mesosoic limestone produce mainly road metal. Abandoned slate quarries occur near Argut in the Ordovician and Silurian slates.

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